FORESTRY

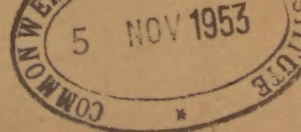
THE JOURNAL OF THE SOCIETY OF FORESTERS OF GREAT BRITAIN

Edited by R. W. V. PALMER

VOLUME XXVI : NUMBER 2

Price
Twelve Shillings and Sixpence

Published by the
OXFORD UNIVERSITY PRESS
LONDON: GEOFFREY CUMBERLEGE
AMEN HOUSE, E.C.4
1953



SOCIETY OF FORESTERS OF GREAT BRITAIN

THIS SOCIETY was formed at Aberdeen in 1925 and adopted its first Constitution at Oxford in 1926. This has been modified several times and the present Constitution became operative in December 1947.

The object of the Society is to advance and spread in Great Britain the knowledge of technical forestry in all its aspects.

The activities include the publication of the journal, the holding of meetings, conferences, and excursions, and the awarding of a medal.

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THE IMPORTANCE OF FORESTRY is being realized more and more in Great Britain. The number of foresters is increasing steadily, and a forestry profession is gradually being built up. It is intended that this Society should be representative of the profession. Those who are not engaged in the practice of forestry or the allied sciences are cordially invited to join the Society as Ordinary Members.

THE SOCIETY'S JOURNAL, called *Forestry*, is usually published twice a year, in January and July. It provides a means for the publication of the results of practice and research both in the growing of timber and in its utilization, including such basic sciences as forest physiology and ecology, forest soils, wood structure, and timber physics, and allied sciences such as forest entomology and forest mycology.

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SOCIETY'S MEDAL. This may be awarded by the Society to any individual who has rendered eminent services to British forestry. Proposals for the award have to be made in the first instance to the Council by a Member of the Council. The regulations for the award will be found in Vol. xx, pp. 80, 81, and in Rule 11.

[*continued on inside back cover*

FORESTRY AND SILVICULTURAL DEVELOPMENTS IN NORTH WALES

By W. A. CADMAN

(*Forestry Commission*)

SUMMARY

After a brief general account of natural conditions, the nine main vegetation types available for afforestation since 1921 are described separately. Preparation of the ground and planting methods are discussed, and this is followed by detailed notes on the relative local values of the species used, on the main problems of policy and management, and very briefly on the problems of protection. The paper is illustrated by two charts which are correlated. The first chart shows the main vegetation types and their ground conditions and the second chart the same types and the tree species which experience has found most satisfactory for planting thereon. There is in addition a table giving up-to-date growth data for the principal species used recently in afforestation.

INTRODUCTION

THE area described comprises the counties of Anglesey, Denbigh, Flint, Caernarvon, Merioneth, Montgomery, Radnor, and Cardigan, which make up the North Wales Conservancy. At the present time there are twenty-nine forests in north Wales which total 73,000 acres of plantations. The first Forestry Commission planting took place in 1921, five forests being in existence by 1925.

DESCRIPTION

(*a*) *Climatic factors*

Wind is one of the major factors which govern tree growth in north Wales. The prevailing wind is from the south-west. In the hills there is a tendency for the wind to follow the main valleys. This results in many local eddies, and there are several examples of curious wind-effects which were unforeseen at the time of planting. Thus there are cases where exposure is worse on the floor of the valley than near the upper planting limit several hundred feet higher. Spurs and ridges which project into the main windstream mostly suffer from blast. There are cases of blast due to up-draught and also unusual down-draughts which are now seen to impinge on certain fairly well-defined areas previously thought to be well sheltered.

Salt-laden wind has caused damage to tree growth in coastal areas, even affecting nursery stocks. Gales on the western seaboard occur on 35 to 40 days in the year, the worst months being January, February, October, November, December with March, April, and September having less frequent gales and May to August the least. But severe, damaging gales often from abnormal directions may occur during any month.

Rainfall is high, especially in the mountains, where 200 inches per annum has been recorded (Snowdon). On the west seaboard the average annual rainfall is in the region of 40 inches, rising fairly rapidly to over 100 inches in places on the high ground. Towards the east the rainfall drops and along the English border is once more in the region of 40 inches.

Snow is a serious factor on the high ground where losses have occurred. It is the unusual wind, accompanied by snow, which is most apt to cause damage. Snow does not often lie continuously for more than 2 weeks on the high ground and is of very short duration on the coastal areas.

Frost occurs for varying periods each winter, although the normal climate in north Wales cannot be said to be severe. Quite mild winters are frequent. Late spring frosts up to the end of May (or exceptionally later) have caused very severe damage to tree growth, the worst years being 1935 and 1943. The years 1948–53 have been remarkably free from spring frost damage.

Spring drought is frequently a factor which influences adversely the use of small plants.

(b) Topography

In Snowdonia the country is typically rugged and precipitous with much rock outcrop and steep-sided valleys. The rivers are fast flowing, often through deep ravines. To the east lies the high plateau of the Denbighshire moors. The rugged country extends south to Cader Idris and Aran Mawddwy. Further south and also to the east of these mountains the general elevation is lower and the hills are less harsh with more rounded contours. The River Dovey flows westwards through such country. Plynlimon and the Cardiganshire hills are bleak and exposed, but their round tops and wide valleys contrast with the precipitous and rugged country of Snowdonia. To the east the high hills fall away towards the English border, where conditions are more equable. Anglesey is a relatively flat county fully exposed to sea winds.

(c) Geology

The greater part of the north Wales forests falls either on the Silurian or the Ordovician slates and shales. In Snowdonia there are some areas of igneous rock with some felsite and basic dolerite. Near St. Asaph and Llangollen there are outcrops of Carboniferous limestone, but forests on this formation are too young to provide information of silvicultural interest yet. The soils vary from shales and shaly loams to alluvial clays with deposits of river gravel in some places. The upland soils are usually rather poor and leached, being deficient in phosphates especially. There is but little podzolization, and although there are places where an incipient pan has begun to form, the soil is remarkably free from hard pan. On the high ground there is usually peat, and in some places peat formation is of considerable depth, as it may also be on some of the low-lying ground.

(d) Vegetation

The main vegetation types on which most of the planted areas in north Wales

are situated may be classified for the purpose of this paper as follows. These types are also set out on the Vegetation Chart (Fig. 1 below).

I. *Juncus* flushes. Areas with free water, usually easily drained and very productive.

II. *Molinia.* Deep peat bog areas: sometimes frost hollows: drainage usually impeded. Often difficult to afforest. (Note: *Molinia* may also be present in Types III, IV*b*, and V, whilst *Calluna* is often present in *Molinia.*)

III. *Erica tetralix*, *Eriophorum*, *Scirpus.* Indicates severely impeded drainage and deep, sour, peat. *Calluna* is often present. This is always a difficult type to afforest. At Gwydyr, Beddgelert, and Coed y Brenin *Myrica* is often present, together with *Molinia.*

IV. *Calluna Moorland. Calluna* is a very variable and rather unreliable indicator and is associated with other species which may be temporarily dominant during a phase in the development of pure *Calluna*, or which may always be co-dominant. *Calluna* moor is usually rather difficult to afforest, and care is necessary as to treatment and choice of species. Peat of moderate depth is present. The most difficult areas are the *Calluna* hardrock outcrops.

IV*a*. *Vaccinium–Calluna.* This is a stage in the development of pure *Calluna*, which is very frequently found on steep north slopes which have been regularly grazed by sheep. Development of pure *Calluna* is often very slow—so, too, is tree growth. The mineral soil is often compact. Thin peat is often present.

IV*b*. *Nardus and Fine Grasses.* This is an earlier stage in the development of *Calluna* moor and results from intensive sheep-grazing over a long period of years. Mineral soil often with a thin layer of peat is compacted by animals.

IV*c*. *Calluna–Bracken.* The invasion of pure *Calluna* moorland by bracken is frequent. Usually the mineral soil is close to the surface and reasonably dry. The bracken is quickly eliminated by whipping in the spring with a consequent reversion to pure *Calluna.*

V. *Erica cinerea*, *Ulex gallii*, *Calluna.* This type usually occurs on dry compact south slopes. Afforestation is always difficult on such sites which are often exposed. Rock outcrops are often present.

VI. *Ulex europaeus and Fine Grasses.* This type, whilst usually also on dry south slopes, generally indicates deeper soil and less exposure. Afforestation is easier, though hard weeding is essential.

VII. *Marram.* In north Wales forests this type is confined to Newborough, where it is associated with a large sand-dune area, much of which is unstable.

VIII. *Dense Bracken.* This usually indicates deep moist mineral soils, reasonably sheltered. (Bracken, of course, regularly tends to invade other types—see IV*c*.)

IX. *Old Woodland Sites* (Coppice, Bracken, *Epilobium*, *Digitalis*, *Rubus*). This type is usually on deep mineral soils which have been associated with a hardwood crop. (Of course old woodlands may occur on any of the foregoing sites.)

(*e*) *Abbreviations*

The following abbreviations are used for convenience:

S.P.	Scots Pine	*Pinus sylvestris* L.
C.P.	Corsican Pine	*P. nigra* var. *calabrica* Schneid.
P.C.	Lodgepole Pine	*P. contorta* Doug.
E.L.	European Larch	*Larix decidua* Mill.
J.L.	Japanese Larch	*L. leptolepis* Gord.
H.L.	Hybrid Larch	*L. eurolepis* Henry.
D.F.	Douglas Fir	*Pseudotsuga taxifolia* Brit.
N.S.	Norway Spruce	*Picea abies* Karst.
S.S.	Sitka Spruce	*Picea sitchensis* Carr.
P.om.	Serbian Spruce	*Picea omorika* Pan.
Ts.	Western Hemlock	*Tsuga heterophylla* Sarg.
Th.	Western Red Cedar	*Thuja plicata* D. Don.
L.C.	Lawson Cypress	*Chamaecyparis lawsoniana* Parl.
Ab.nob.	Noble Fir	*Abies nobilis* Lindl.
Ab.gr.	Grand Fir	*Abies grandis* Lindl.

PREPARATION OF GROUND AND PLANTING

(*a*) *Scrub*

In the early years the practice was one of complete clearance and complete replanting followed by the minimum weeding necessary to get the plants through. There was a tendency to treat all regrowth of natural species as weed growth and to cut it out. There were a few notable exceptions, the best example of which is to be found at Gwydyr Forest in Waterloo Wood. Here dense natural ash (*Fraxinus*) regeneration appeared in patches. Weeding was given up after a year or two, with the result that a promising ash crop has resulted, with some sycamore (*Acer*). In these groups the original plants of N.S., D.F., and S.S. are now almost entirely missing.

In the early thirties ring-barking of valueless scrub in early summer was practised, areas thus treated being usually planted with a shade bearer—D.F., Ts., Ab.gr., Th., and, in wet places, N.S. were the species most favoured. The method was most successful, since the shade-bearing conifers benefited from the gradually decreasing shade, weed growth was much less, and costs were greatly reduced. (At that time there was no market for firewood or low-grade hardwood scrub, which was very costly to clear and burn.) As the new crop grew through the dead scrub some damage to leaders occurred, but now that these trees have grown through the scrub and reached the thinning stage it is evident that material damage has been negligible. The disadvantage of this method was that the ringed scrub was most unsightly for a number of years, resulting in considerable adverse criticism in places of local beauty. The present policy is only to ring unsaleable scrub which is reasonably remote from the public eye! One exceptional case of

ringing is worthy of special mention. At the Bryncynfil section of Dovey Forest there was a very inferior oak wood (*Quercus*) growing on a dry, heather-clad rock outcrop. It was clear that none of the normal shade-bearers would have been likely to do well on such a site. The area was therefore planted with S.P., special care being taken to use good plants and to do the ringing thoroughly. As was anticipated the oak died more quickly than normal on this dry site, the S.P. survived the early year or so of shade, and now a very promising stand of pine is ready for the first thinning.

With the conclusion of the war and the post-war increased planting programmes, there has been a great increase in the replanting of old woodland areas carrying scrub. Each case has to be considered as a separate problem and treatment (and also the supervision thereof) is often detailed and always difficult. So far as possible full use is made of all useful regeneration and regrowth. More hardwoods are being used than in the pre-war period, as more suitable land has been acquired. Large-scale mechanical scrub-clearance experiments are being undertaken, both with bulldozers and Rotovators. So far, however, no satisfactory, practical, and economic solution has been found. Nor has a selective weedkiller been found which is economic and satisfactory.

(*b*) *Draining, turfing, and ploughing*

In the early days of the department little information was available regarding the plantability of wet land, although it was realized from the start that drainage was essential. In the light of experience and of improved technique there has been a gradual extension into areas which were not at first considered to be plantable.

Up to 1929 in north Wales all plants were notched, usually with a mattock, direct into the surface. On the poorer sites checked growth resulted and plants were slow to come out of check. In 1929 the spoil from drains was spread and used for planting. In 1930 turf planting on a planned layout commenced, coupled with a much more intensive drainage system consisting of three stages: major and minor contour cut-off drains to prevent water from coming on to the area being drained, leads for springs and watercourses to take water out of the area, and a filling in of the intermediate ground with turf drains to provide the turves on which to plant. This method is still current practice in all areas which cannot be mechanically drained (i.e. ploughed).

Turf planting resulted in a very considerable extension of planting on land hitherto considered to be doubtful; it reduced the period of check and on many areas reduced weeding costs. But it soon became evident that whilst there were great benefits from this method applied to grassy areas and on *Molinia* ground, results were not so satisfactory on dense heather areas, such as are found on the Denbighshire moors at Clocaenog Forest. It was at this forest that the first experimental ploughing in Wales was carried out in 1934. A Fordson tractor and a single-furrow Ransome plough were used to turn out furrows at 5 feet spacing, planting being done on top of the out-turned furrow. In 1935 the first caterpillar tractor was used to pull a double-furrow Oliver plough. The furrow was shallow, averaging 4 to 6 inches. From this period to the outbreak of war the use

of ploughing was extended to several forests (Kerry 1938, Dovey 1939, Hafren 1939, &c.) and many different types of plough were tried. Development of types of plough, ploughing tackle, and ploughing technique has been rapid in the post-war years. It is now the policy to plough everything which it is practicable to plough economically. Very small areas do not justify the expense of bringing in ploughing equipment, and of course very steep slopes and rocky broken country cannot be ploughed. Where ploughing is not possible, then the former methods of surface-planting firm ground and draining and turfing wet ground apply. In addition to straightforward turf planting, it has been found that spruces planted on Types IV*a* and IV*b* (grass/Vaccinium) on slopes which cannot be ploughed respond well to hinge turfing. The hinge retains moisture during periods of drought.

(*c*) *Planting methods*

There has been on the whole very little change in planting methods, the bulk of the planting still being carried out with a mattock. At some forests a semi-circular spade is used for plough planting. A narrow, wedge-shaped planting spade with a foot rest, copied from an American pattern, has been used successfully, but on a small scale, for planting seedling oak.

(*d*) *Manuring*

Early research work showed that basic slag gave some beneficial effect and that this lasted for several years. As the quality of basic slag is variable, it is now current practice to use ground mineral phosphate. But it is only used to a limited extent on the worst sites (e.g. Vegetation type III: *Erica tetralix*, *Eriophorum*, &c.).

CHOICE OF SPECIES

A Species Chart, correlated with the Vegetation Chart, is given as Fig. 2. It is intended only to be an approximate guide to current practice in north Wales as to the choice of species. It must be appreciated that vegetation types merge one into another and are often not as clearly defined on the ground as on the Chart. The selection of species must be based primarily on local knowledge. There are several factors which are not included in the chart (e.g. elevation, aspect, rainfall, &c.) which must also be taken into consideration.

In the early years S.P. was used for all rocky areas: E.L. was fairly widely used on sites above the danger of spring frost where the soil was thought to be reasonably good: J.L. was used on many of the best sites indicated by dense bracken: S.S. was planted on the low-lying wet ground and N.S. on similar ground at higher elevations. D.F. was used on deep soils, reasonably sheltered. It was known from experience at Lake Vyrnwy that C.P. was subject to the fungus *Brunchorstia destruens* in high rainfall areas at high elevations and therefore this species was only used to a very limited extent. A few trial plots of other species such as Ts., Th., L.C., Ab.nob., and Ab.gr. were planted, but such planting was on a very small scale. Some hardwoods, especially beech (*Fagus*), were planted, mainly as fire-breaks and amenity belts.

It was very soon realized that S.S. withstood exposure much better than N.S., but that N.S. was less susceptible to damage by spring frosts than S.S. The choice

of sites for these two species was therefore reversed and so far no species has been found to withstand high-elevation exposure, under climatic and edaphic conditions in north Wales, better than S.S. although Ab.nob. shows considerable promise on such sites. It was not until the early thirties that it was realized that N.S. is not a suitable species to plant on heather areas, although pure S.S. was often not entirely satisfactory either. Yet the advent of ploughing resulted in a much higher proportion of success, on such areas, than previously. S.S., which is the most widely used of all species in north Wales, has proved to be much more rapid in getting away than N.S. on all sites where there is no serious adverse factor affecting its growth. Some bad 'frost cracks' appeared in both species during the 1947 winter, S.S. being affected worst. Stem analysis revealed the cause to be drought. There are some very fine stands of S.S. growing in north Wales, and even on some of the poorest sites growth is satisfactory. Sales of Christmas trees mainly from N.S. thinnings have been the most paying of all sales made and have brought in over £20,000 each post-war year.

Picea omorika has been used successfully in frost hollows and even on heather ground. It grows rather slowly and suffers from moderately severe exposure, but in most cases it will make a useful crop and it has already coned well. On hardwood sites it suffers severely from Honey fungus (*Armillaria mellea* Fr.).

As a result of experiments in Scotland the use of pine/spruce mixtures for heather areas was applied in the early forties. The difficulty of subsequent treatment of single-row mixtures of S.P./S.S. led to planting 2-row:2-row mixtures on all heather ground. This practice is still current. It was soon evident that S.P. suffered very severe 'browning' during winter, especially near the western seaboard and at high elevations, whether planted pure or in mixture. In extreme cases, such as the highest parts of Myherin Forest in Cardiganshire, this species has failed to maintain any upward growth and it takes on a recumbent, bush form. But on the Denbighshire moors, at Clocaenog, S.P. has succeeded remarkably well even at elevations well over 1,000 feet.

In the early thirties, plants of P.C. were found germinating in the S.S. and D.F. seed-beds. The resulting plants were used experimentally: in the first years almost entirely to beat up other species, usually S.S. The results were promising, and this species now has a regular place in the planting requirements in north Wales. We have little knowledge of crops older than 18 years, but so far it has proved itself to be a very accommodating tree, growing on very poor sites and being able to withstand both summer drought and also a high degree of winter waterlogging. Indeed it grows better on really poor sites than on deep, good soil where it is not satisfactory owing to coarse irregular growth. It also withstands a high degree of exposure: more so than S.P. There are several forms, varying from a rather coarse, heavily branched, dark green type, believed to be the coastal form, to a finer branched, cleaner type, with paler foliage, believed to be the inland race.

C.P. has been used rather more frequently during the post-war years. The sand-dune forest of Newborough is primarily a Corsican pine forest. Also a number of small coastal areas contain rock outcrops exposed to sea winds at reasonably low elevations: C.P. has been used for these.

The Mountain pine (*Pinus uncinata* Ramond) was planted at several forests in the early years. Its height growth has always been very slow and it is of bushy form. There are reasons for using the species in mixture with S.S. on certain sites: the dense spreading growth kills out heather, gorse, &c., whilst the slow height growth

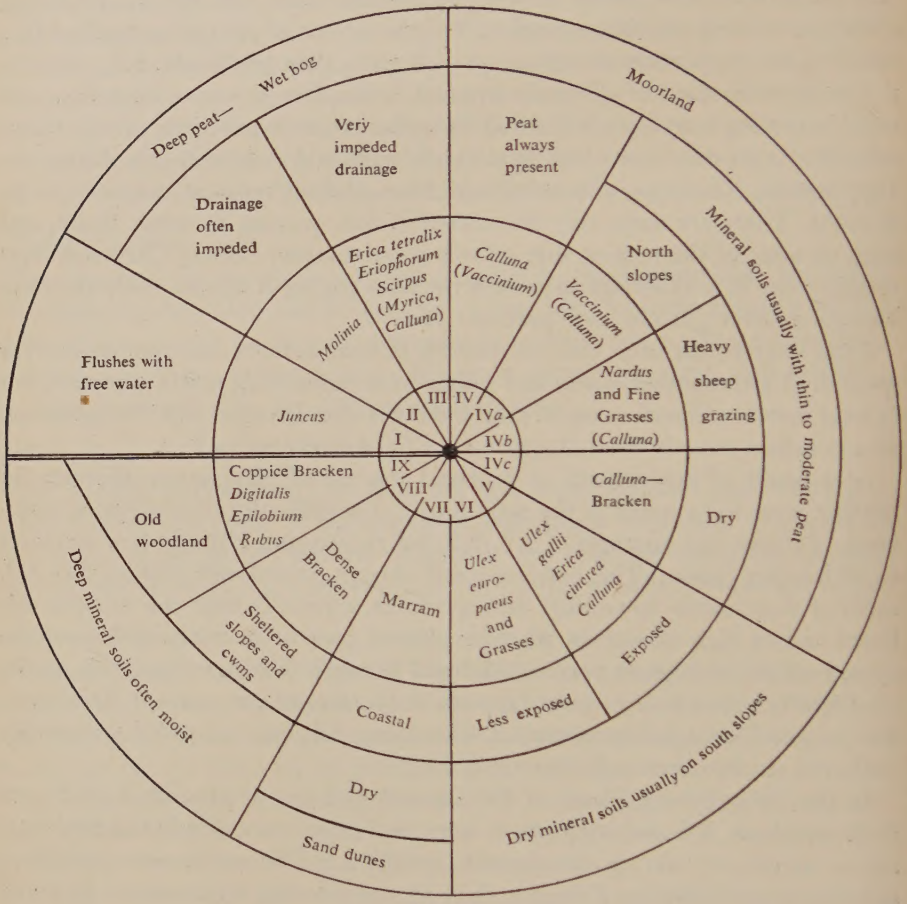

FIG. 1

Vegetation Chart

means that there are no awkward thinning problems as the S.S. soon tends to form a pure crop. Other pines are being used as trials, and one worthy of mention is *Pinus peuke* which shows considerable promise on poor heather ground at Beddgelert and elsewhere. (It is not yet known whether it is resistant to rust fungi.)

E.L. has been one of the Department's greatest disappointments. Nowhere in north Wales has it done really well. In all cases it has been subject to some die-back and in many cases this has been devastating. Those individual trees which reach the second thinning stage usually recover well and grow fairly satisfactorily,

but they are few in number. Most E.L. areas have been opened up and underplanted or they are scheduled for this treatment.

J.L. has been very widely used, and this species will always have a very important place in north Wales. Its rapid growth and quick establishment make it the most

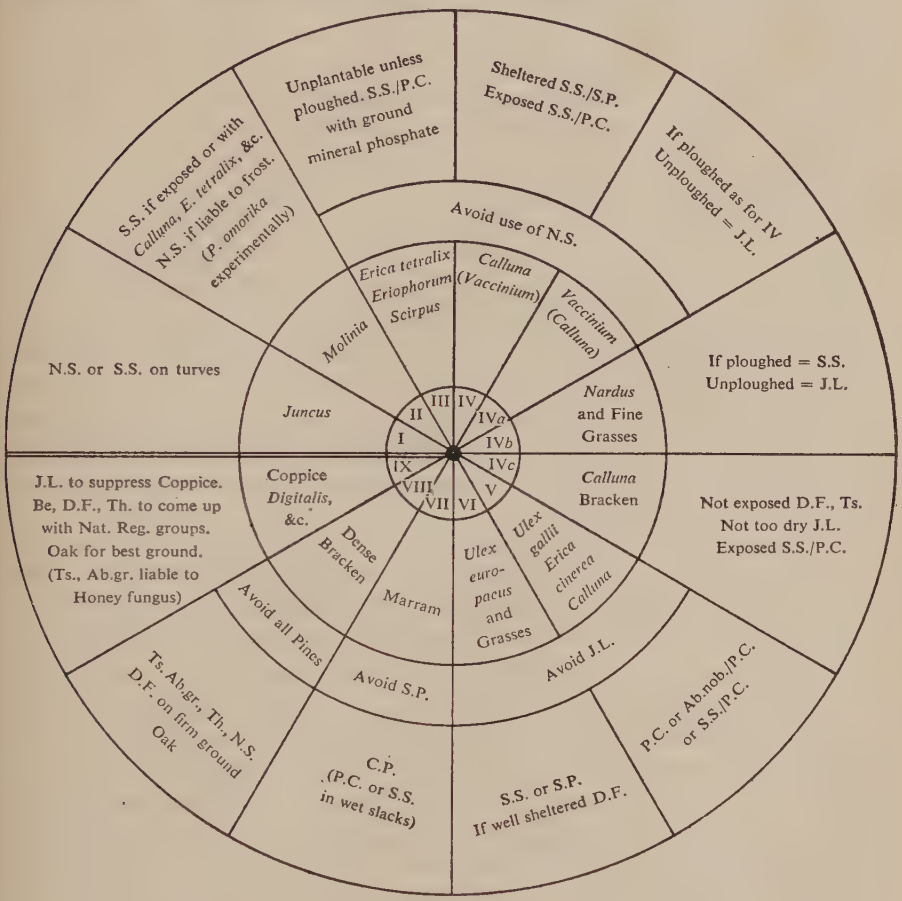
Unplantable unless ploughed. S.S./P.C. with ground mineral phosphate
Sheltered S.S./S.P. Exposed S.S./P.C.
If ploughed as for IV Unploughed = J.L.
S.S. if exposed or with Calluna, E. tetralix, &c. N.S. if liable to frost. (P. omorika experimentally)
Avoid use of N.S.
Erica tetralix Eriophorum Scirpus
Calluna (Vaccinium)
Vaccinium (Calluna)
Molinia
N.S. or S.S. on turves
Juncus
Nardus and Fine Grasses
If ploughed = S.S. Unploughed = J.L.
III
IV
II
IVa
I
IVb
IX
IVc
VIII
V
VII
VI
J.L. to suppress Coppice. Be, D.F., Th. to come up with Nat. Reg. groups. Oak for best ground. (Ts., Ab.gr. liable to Honey fungus)
Coppice Digitalis, &c.
Calluna Bracken
Not exposed D.F., Ts. Not too dry J.L. Exposed S.S./P.C.
Dense Bracken
Marram
Ulex gallii Erica cinerea Calluna
Ulex europaeus and Grasses
Avoid all Pines
Avoid S.P.
Avoid J.L.
Ts. Ab.gr., Th., N.S. D.F. on firm ground Oak
C.P. (P.C. or S.S. in wet slacks)
S.S. or S.P. If well sheltered D.F.
P.C. or Ab.nob./P.C. or S.S./P.C.

FIG. 2

Species Chart

economic tree for killing out coppice. It forms a quick and effective fire belt. It produces thinnings more quickly than any other species (except H.L.). It is particularly useful for planting on steep slopes which have been compacted by generations of sheep-grazing and which are not capable of being ploughed (e.g. Vegetation Type IV*a* and IV*b*). J.L. (and to a lesser extent S.P. and P.C.) does not benefit from being planted on ploughed furrows. There is a strong tendency for it to form a bad butt sweep when planted on ploughed ground. There is so far no evidence that the growth of J.L. on reasonably good sites will fall off at 30 years or so. Provided that thinnings have been heavy and often enough, the rapid

growth rate is maintained and there is no indication in the oldest plantations (30 years) of any fall off in increment. There has been one bad case (Coed y Brenin), and a number of individual instances elsewhere, of canker on J.L. This is not similar to E.L. canker. In the case of J.L. the bark dies and falls off leaving the tree partially ringed. The extent of this trouble is very limited. The cause is not yet known. J.L. has been used in mixture with S.S. at several forests. Generally the J.L. has grown too fast at the outset for the S.S., which has been suppressed. But at Gwydyr there is a most successful example of the mixture of the two species. Satisfactory J.L./S.S. mixtures have been achieved by delayed beating up of S.S. with J.L.

H.L. has only been used on a limited scale. Growth has been rather faster than, but otherwise similar to, that of J.L.

D.F. was planted in the early years on deep and often moist soils. This led to frequent trouble with windrock just before the canopy stage was reached: sometimes much earlier. Heavy expenditure on staking such areas was incurred. At some forests, notably Radnor and Kerry, this species was planted at elevations (up to 1,200 and 1,400 feet above sea-level) which now are seen to have been too high. Resultant growth, though vigorous, was coarse. In many areas there have been severe attacks of *Chermes*, and the Fraser River variety, which appeared to suffer less from this trouble, later developed *Rhabdocline pseudotsugae* in several instances. D.F. is a relatively poor shade-bearer in north Wales. All these troubles led to a reduction in the use of D.F. at the end of the thirties. Since the war D.F. plantations have reached the second and even third thinning stage and there has been a great improvement. This species is now planted on reasonably sheltered *firm* soils. In some instances a single-row mixture of S.S./D.F. has been planted, since a very clean type of D.F. often occurs where the two have been mixed accidentally (i.e. through beating up or because of wet flushes of S.S. in D.F. areas).

Ts. An appreciation of the importance of this species is one of the principal recent developments in the assessment of species grown in north Wales. Plantable stocks of this species have always been in short supply, but it has been fairly widely used in small blocks. Its ability to withstand shade led to its use for underplanting, for which purpose it has proved to be the most satisfactory of all species tried. On old hardwood areas it is liable to death by honey fungus: it will stand reasonable exposure, though the growth in the first years may be slow and it may even become damaged by blast. It will grow on a variety of sites, including good heather ground, bracken ground, and intermediate soils including peaty ground. Volume production is greater than any species other than Ab.gr., and S.S. on good sites. So far it has shown no serious tendency to fluting in north Wales.

Th. This tree has not been used to the same extent as Ts. It shows good promise and even where it has suffered seriously from an attack of *Keithia thujina*, it has recovered well. There is a tendency to butt swellings in places. It withstands shade well.

L.C. The two main troubles with this tree have been found to be damage by voles, especially if near *Molinia* areas, and liability to multiple leaders. It has been found to be rather frost-tender during the early years after planting, but once

established, it will thrive on a variety of sites, even on heather-gorse and *Molinia* areas.

Ab.nob. Originally used mainly for amenity, it has been found that, although a slow starter, Ab.nob. will withstand much exposure. It will also tolerate rather drier sites than S.S. It bears cones from an early stage nearly every year. It is hardy and not frost-tender.

Ab.gr. On sheltered good sites this tree is the greatest volume producer so far planted, although it is another slow starter. It is, however, sensitive to exposure and often suffers from cold winter winds. So far it has coned very badly.

Other conifers such as *Cryptomeria japonica*, *Sequoia gigantea*, *Sequoia sempervirens*, and even *Metasequoia* are being used on a small scale, but they are as yet too young to provide useful information, although the first named shows considerable promise.

Of the hardwoods, beech has been found to grow at quite high elevations even on heather sites. But it is usually very rough. Birch (*Betula*) has been difficult to establish on dry sites, but has done well at Clocaenog in *juncus* flushes. Sycamore has proved very difficult to establish, and ash, too, even on good sites has been disappointing. Red oak has grown very vigorously and is more accommodating than sessile oak. It is clean and reasonably straight on most sites where it has been planted. Most of the oak plantations are of post-war origin, on good sites of old woodland, and it is too soon to assess results. *Robinia* has been grown in a few places: it grows fast, but tends to fork and is subject to much breakage. Tulip-trees (*Liriodendron*) have also grown fast, but they are very prone to snow damage. One of the most interesting species tried is *Notofagus procera*. There are two plots, the best of which is nearly keeping up with J.L. adjoining (both planted in 1937) and is superior to the beech in the general area. The poplars *P. trichocarpa* and *P. generosa* have both grown very well and vigorously in north Wales, where so far they have been free from serious canker. Common alder (*Alnus*) is a poor tree which very frequently suffers from dieback. Grey alder has not been planted, although some cases of recent natural regeneration are under observation on old woodland sites (Mathrafal). Oregon alder showed great promise at first, growth being rapid and straight. However, it is very prone to sudden dieback in the crown and cannot be relied upon even on very good sites. Cherry (*Prunus*) has been planted on a small scale on good sites and is very satisfactory.

It is interesting to note that natural regeneration has occurred from the following species planted by the department: Dense—S.S., Th., J.L., and L.C.; Sporadic—E.L., S.P., N.S., Ab.nob., and D.F. In addition to the above, good seed is fairly regularly collected from C.P., P.C., Ab.nob., Ts., and *Picea omorika*, though the last two have not coned very frequently yet. Table I gives details of growth for the commoner species used.

MANAGEMENT

Most aspects of management are common throughout the Commission's forests and are treated in a similar manner, but both conservancies in Wales differ from some other conservancies in regard to the important question of thinning.

TABLE I. *Growth data by species*

Species	*Locality*	*Year of planting*	*Year assessed*	*No. of thinnings*	*Standing*				*Removed*		*Total vol. per acre*	*Mean annual increment*	*Quality class*	*Remarks*
					Total Ht.	*Av. vol. per tree*	*Trees per acre*	*Cube per acre*	*Trees per acre*	*Cube per acre*				
C.P.	Gwydyr	1921	1951	3	52½′	6·05	358	2,161	796	1,327	3,488	188	I	..
J.L.	Dovey-Penlan	1939	1952	1	36′	1·9	640	1,216	460	750	1,966	151	> I	14 years old
	„ Esgair-Llwyd	1934	1952	2	44′	3·3	460	1,518	720	1,050	2,568	142	> I	Average site. Compare with H.L. adjoining
	„	1930	1952	3	52′	4·5	320	1,440	870	1,400	2,840	129	> I	„ „ „
	Beddgelert	1929	1951	1	27½′	0·67	904	620	896	390	1,010	46	III	1,350′ High-elevation
	„	1929	1951	1	23′	0·49	935	459	576	231	690	..	III	1,450′ Plots
H.L.	Dovey Corris Esgair Llwyd	1934	1952	2	39′	3·0	500	1,500	800	1,190	2,690	149	..	Average site (compare with 1934 J.L. above which adjoins H.L.)
D.F.	Gwydyr	1928	1951	3	49′	3·75	430	1,612	578	610	2,222	96	III	Periodic increment 208
	Dovey Corris	1927	1952	3	54′	7·3	330	2,409	850	1,375	3,784	151	II–III	..
	Gwydyr	1921	1951	3	62½′	8·0	241	1,922	694	1,359	3,281	109	IV	Periodic increment 239
N.S.	Dovey	1927	1950	2	43′	1·7	1,020	1,785	640	815	2,600	113	> I	..
	Coed y Brenin	1925	1951	3	58′	6·1	462	2,830	720	1,290	4,120	158	I	..
S.S.	Beddgelert	1929	1951	1	24½′	0·75	1,157	876	711	420	1,296	59	< V	1,350′ exposure plot
	Dovey Corris	1927	1952	2	50′	4·7	550	2,585	600	1,150	3,735	156	II	..
	„ „	1927	1952	3	48′	7·3	420	3,066	850	1,750	4,816	192	II	..
	Gwydyr	1923	1951	3	77′	15·2	232	3,526	866	3,442	6,968	249	> I	..
Ts.	Dovey Corris	1928	1952	4	60′	9·5	310	2,945	900	2,310	5,255	219	..	The last thinning sold at £99 per acre
	Gwydyr	1927	1951	3	53½′	3·8	498	1,896	665	979	2,875	120	..	..
Ab.gr.	Dovey Corris	1928	1952	3	45′	6·0	390	2,340	670	1,540	3,880	162	..	Adjoins 1928 Ts.
	Gwydyr	1927	1951	3	60½′	6·2	362	2,238	726	1,453	3,691	261	..	..
Ab.nob.	„	1927	1951	3	37′	2·0	906	1,803	163	218	2,022	84	..	..
Th.	Dovey Corris	1932	1952	1	39′	2·1	800	1,680	236	472	2,152	107	..	Recovered from severe *Keithia* attack 10 years after planting
	Gwydyr	1930	1951	3	34½′	1·3	969	1,248	188	329	1,577	75	..	..
L.C.	„	1927	1951	2	38′	2·1	990	2,118	438	641	2,759	115	..	..

Since the production of large quantities of pitwood will naturally follow with the ageing of large areas of thriving young plantations, the most serious national shortage is the shortage of saw timber. The Director holds the view that one of the main functions of the Commission is to produce the maximum quantity of saw timber at the earliest possible moment and, under our conditions, the one way to ensure this is by heavy thinnings. Some foresters object that this will lead to the production of coarse timber. The counter argument is that, in our present circumstances which may continue for some years, size is of the first importance, and the experience of two wars shows that the small difference in coarseness which may follow grades of density within the silvicultural limits of close-grown plantations is of little consequence either in terms of price or usage. Moreover, home-produced timber from the more open plantations is not inferior to much of the imported timber which has been arriving here in recent years. Other important effects of early and heavy thinning are the provision of early financial returns and a possible increase in the total production of timber. Hence a policy of early thinning—which has occurred in some J.L. as early as 9 years after planting—and heavy thinning is in force in Wales.

An earlier remark that up to 30 years of age J.L. has not shown any tendency to fall off in growth indicates that some doubt exists as to the final status of this species, that is, how long it will maintain a rapid rate of growth and whether it will be profitable to grow on beyond a certain stage. The current opinion is that in order to keep it growing rapidly it may be necessary to give ample room for the development of a large crown, in which case the standing volume will be much less than is possible with other species and less profitable. If this proves to be the case there are two alternatives, either to fell at a relatively early age or to thin very heavily and underplant. The former method has all the objections of clear felling coupled with restricted production of large timber sizes, whereas the second alternative may be free from these objections and efforts are being made in Wales to test this. It implies ascertainment of correct thinning densities at different stages and the most suitable species for underplanting in varying conditions.

In hilly country the extraction of produce is frequently difficult and calls for an adequate road system. In north Wales road construction has therefore become an important facet of management.

PROBLEMS

Whilst the success of afforestation projects in north Wales is evident at every forest for all to see, in some cases even exceeding all earlier expectations, there are still problems which remain to be solved. A discussion of these problems is of interest to all foresters.

The general problem of reducing costs of all operations, without loss of efficiency, is always in mind, but it does not come within the scope of this paper. Nor do the many problems of extraction and engineering which are very much in the forefront now.

From a silvicultural point of view some of the most interesting problems concern those sites which have proved most difficult and on which growth has been

slow and disappointing. The factors involved are usually impeded drainage, lack of aeration, and competition with the natural vegetation. Another problem about which there is still much to be learnt, notwithstanding the considerable experience already gained, is that of wind blast. The treatment of coppice, scrub, and rhododendron areas provides a great variety of difficulties. More advanced problems will concern regeneration of the existing crop. This stage has not yet been reached except in the case of certain J.L. stands, where it is now desirable to introduce a more valuable species by underplanting. A similar problem will be the conversion to more valuable species of such pioneer species as P.C., planted on poor sites, to provide a soil cover and forest conditions. (It is perhaps worth mentioning here that there are many instances of N.S. woodland, felled during the war and replanted with S.S., where the growth of the second crop to date is outstanding.)

Of these silvicultural problems the first is perhaps the most difficult because the conditions are naturally so adverse. The worst sites are Types III and V. Indeed much of the ground covered by Type III is unplantable. Where advance draining can be carried out, so as to permit subsequent ploughing by the single-furrow Cuthbertson plough, then there is a marked improvement in the natural vegetation and there are strong indications that afforestation will be successful. Such a case can be seen at Talycefn bog, Clocaenog Forest. The original vegetation was *Erica tetralix*, *Calluna*, and *Eriophorum*: the peat was sour and many feet deep, and even *Calluna* grew but poorly. The whole area is in a large frost basin. After Cuthbertson ploughing, S.S., N.S., P.om., and P.C. were planted. The water-table fell and the upper layers of peat have dried out: the *Eriophorum* has nearly disappeared and *Deschampsia* (*Aira*) *caespitosa* has come in, *Calluna* is now growing vigorously, and both S.S. and P.C. are growing satisfactorily. N.S. and P.om. are less vigorous, but they have not gone into check. Since planting in 1948 the area has fortunately escaped any severe spring frost. The area shows what can be achieved by the full application of the latest technique. Elsewhere there are similar areas where ploughing has not been possible and where even intensive drainage has failed to provide conditions for satisfactory growth. Type V, Bell-heather/Dwarf gorse, is always difficult; the main factor appears to be competition for moisture during dry periods during the growing season. So far P.C. has been the most successful species.

In Snowdonia, in the forests of Gwydyr, Beddgelert, and also in parts of Coed y Brenin another very difficult type of ground is found in what the late Chairman called the 'Hardrock areas', to distinguish them from the soft rocks, or shales, which weather easily and normally provide a reasonably uniform cover of good soil. The hardrocks are of various types, mainly igneous: they are massive, fissured but little, and weather very slowly and frequently outcrop so that the soil cover is discontinuous. The vegetation may not be so discontinuous because where the dip of the rock coincides with the slope of the land heather may grow on a thin layer of peat. Where natural drainage is held up by a lip of rock, pockets of deeper peat form, often strewn with boulders and mixed with glacial deposits. Here the vegetation is often a mixture of *Myrica*, *Erica tetralix*, *Molinia*, and

Calluna. Drainage is difficult and ploughing impossible, whilst frost is often a factor, so that such sites are bordering on the unplantable. S.S. is disappointing and at Gwydyr N.S. has proved rather better. P.C. usually grows reasonably well, but it may be unstable on the wetter areas. More research work is required, particularly so far as spruce/pine (including Mountain pine) mixtures are concerned.

On the poor, thin, heather ground P.C. has proved to be the best tree of all species used to date. It is intended to try Ab.nob./P.C. mixtures on the better parts of such heather ground.

Another difficult site, often associated with the hardrock areas and the *Myrica* type described above, is Tussocky *Molinia*. Glacial boulders and grey clay are usually present, so that draining and ploughing is difficult. Where ploughing is possible, S.S. gets away well; otherwise growth is very slow and disappointing.

So far as old woodland, coppice, and rhododendron areas are concerned, the problems arising are most recent, in that such areas have only come forward for planting to any appreciable extent since the war. No satisfactory answer has been found for dealing economically with rhododendron. Burning in dry weather is usually only successful if dry bracken is present to get the fire going well: even then regrowth from the stools is strong and the dead 'sticks' make weeding after planting difficult. Pulling out by tractor is simple but costly, and the disposal of the roots and brash is even more costly. Where rabbits are not present, it is cheaper to have the heaps piled up and plant around. But there are few rhododendron areas which are not rabbit-infested. Each case of hardwood scrub and coppice has to be treated on its merits, and it is not possible in this paper to cover the many and varied problems which arise.

PROTECTION

Fire protection and its many recent developments does not come within the scope of this paper, and space does not permit a very full report of the various animals, insects, and fungi which have caused trouble. Rabbits are a serious problem, and their increase in areas outside the Department's control make small acquisitions especially difficult to keep clear. Foxes are troublesome if only because nearly every fox in Wales is believed to have been born and bred in a Forestry Commission plantation! The Department employs full-time trappers, and in addition there is close liaison with the Ministry of Agriculture and Fisheries Chief Pests Officer, who is consulted over the amounts of the subscriptions which the Department makes to those fox destruction societies which are considered worthy. Most common forest insect pests and some unusual ones have occurred from time to time. Serious trouble has been avoided, however, and *Neomyzaphis abietina* on S.S. is probably the most noteworthy and certainly the most widespread. The sudden periodic occurrence of this insect is always rather surprising, but the rapid recovery afterwards (so far) has been no less remarkable. Of Fungi, *Rhabdocline* has been prevalent and serious on the Fraser River D.F.; *Brunchorstia* has caused heavy losses of C.P. in high-rainfall, high-elevation areas. But the most

serious of all has been the dieback of E.L., which has been so widespread as to reduce the further planting of this species to a minimum. Research plots have shown that the Scottish races, though not immune, are less susceptible than the Austrian, Swiss, and Italian races.

ACKNOWLEDGEMENT

This paper is published with the permission of H.M. Forestry Commissioners.

THE GROWTH OF SITKA SPRUCE ON SHALLOW SOILS IN RELATION TO ROOT-DISEASE AND WIND-THROW

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SUMMARY

The paper considers in detail the evidence from the examination of some Sitka spruce (*Picea sitchensis* Carr.) 35 to 50 years old, and old enough therefore to begin to reflect the potentialities of the sites occupied which are normally considered suitable for the species. The examination was made to ascertain what factors other than parasitic infestations or infections were acting to cause the thinning of crowns, the death of trees, and the susceptibility to wind-throw. In these shallow soils, factors of fundamental importance are those which determine the regularity of the supply of water and air, and it is considered that where, as in the cases examined, the soils are mainly intractable, early development of disease and of wind-throw will have to be expected.

THE significance of the subject here discussed lies in the considerable importance which Sitka spruce has come to occupy in forest economy in Britain; and in the fact that in recent years there have been increasing, though in terms of area not yet important, instances both of wind-throw and the dying in groups of this species. Added to this, reports have also increased which indicated the possible serious effect which defoliation by the green spruce aphis, *Neomyzaphis abietina*, was having in some localities, even to the extent of causing death. Various reports of the infestation of Sitka spruce by bark beetles have also been received. The woods visited are of interest in connexion with these matters, firstly, because they contain Sitka spruce of from 35 to nearly 50 years of age and therefore old enough to begin to reflect the real potentialities of the sites occupied and, secondly, because the plantations occur chiefly on shallow soils, usually peat-covered, on which in other places Sitka spruce usually has shown favourable growth once it has become established after planting. The question to be asked of these older plantings was thus: what, if any, factors other than parasitic infestations or infections are acting to cause the thinning of crowns, the death of trees, and susceptibility to wind-throw? This is the question which an attempt is made to answer.

THE SITUATION OF THE PLANTATIONS AND THE GENERAL CHARACTER OF THEIR SITES

Kyloe Woods lie 5 miles north of Belford in northern Northumberland on the northerly end of a low ridge of hills. The annual rainfall of this region is low and amounts to about 25 inches. The soils relegated to forestry are usually rather shallow, and if topographical drainage is good the species ordinarily used in conifer plantations have been Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* Karst.), and European and Japanese larch (*Larix decidua* Mill. and *Larix*

TABLE I. *Vegetation and soil characteristics of sites examined*

Group No.	*Situation*	*Type of ground vegetation*	*Previous usage*	*Soil group*	*Surface drainable soil*		*Subsoil*		*Topographical drainage*
					Texture	*Depth (in.)*	*Texture*	*Drainage*	
1	Windy Hill, Canonbie	Nil (probably originally *Rubus fruticosus* under oak)	Agricultural fields	B.F.S.	Sandy loam	12–24+	Sandy clay	Impeded	Moderately good or good
2	Kyloe, Old Wood 18	Nil (probably as 1)	Oak wood	B.F.S. gley	Clay loam	9·5	Clay	,,	Moderately good
3 (*a*)	*Kyloe, Old Wood 14	*Rubus idaeus; Juncus; R. fruticosus; Deschampsia caespitosa; Dactylis*, and other grasses	Woodland	Meadow	,,	11·0	,,	,,	Very poor
(*b*)	Kyloe Crag	,, ,, ,,	? Rough grazing	Peat	Peat	9–18	Sandy clay	,,	,, ,,
(*c*)	Kyloe, Archer Beck Wood	Usually nil; in gaps much as 3 (*a*)	Woodland	,,	,,	9–24	,,	,,	Poor or very poor
4 (*a*)	Moorburnhead Plantation	*Molinia caerulea*	Rough grazing	,,	,,	9–15	,,	,,	Usually poor or moderately poor; sometimes moderately good
(*b*)	,, ,,	*M. caerulea* with *Sphagnum* dominant in wetter places	,,	,,	,,	3–6	Peat (over sandy clay)	,,	Very poor

* The 'wind-throw' patches in Windy Hill Plantation, Canonbie, are very similar.

leptolepis Gord.). The rate of growth is often very moderate, and spruce, in the young plantations commonly seen, often does much less well than either pine or larch. Sitka spruce have been planted in Kyloe Woods either in water-receiving sites in which topographical drainage is poor and marshy conditions tend to prevail, especially when not covered by forest, or on shallow clay soil which from its very nature is water-retentive. The sites most commonly chosen occur in the bottom of narrow and usually shallow valleys in which the prevailing soils either consist of shallow peat or are meadow soils of heavy texture, both being of a fertile type in so far as they are drained. Plainly these sites were chosen because their water-receiving character and consequent wetness or, in the case of clay soils, the water-retentive nature of the soil, was considered to counteract the relatively low rainfall and to provide conditions in which water-supply was adequate for a tree of the nature of Sitka spruce.

The plantations seen near Canonbie in Dumfriesshire covered a more varied range of soil. The annual rainfall in this district is much higher than at Kyloe and amounts to about 50 inches a year. There is a marked tendency to plant Sitka spruce more generally than at Kyloe. The soils observed, on which this species occurred, are of five main types, viz.: (1) well-drained loam; (2) meadow soils which occurred usually as ill-drained patches in areas of loam; (3) shallow fertile peat bearing a ground vegetation very similar to that on much of the Kyloe valley peat and plainly providing essentially the same class of soil; (4) shallow hill peat of fertile type; and (5) deeper and in places really deep hill peat, ill-drained and of poor character for root development except in a very thin superficial layer.

Peat formed the most common types of soil and, in point of area, the most important. There is no need to discuss the two general situations separately; the Kyloe sites fit in entirely with the Canonbie sites for this purpose and together they provide a series, the characteristics of which are summarized in Table I and Fig. 2. It is not possible to give any proper indication of the type of ground vegetation which these soils would naturally bear because in some cases this had been killed by the shade of the spruces; but the brief descriptions in Table I will give some idea of its nature.

Certain points of importance arise from this information: *firstly*, all the sites, with the probable exception of the *Sphagnum* patches on the deeper Moorburnhead peat, have appreciable soil layers which are well aerated (Fig. 2) and which it is unlikely, judging by the vegetation, are deficient in nutrients to any critical degree; *secondly*, with the exception of the deeper aspects of the sandy loam on Windy Hill, this well-aerated layer of soil is shallow and, therefore, the permanent rooting depth of the trees must also be shallow (Table II); *thirdly*, topographical drainage is usually, though not always, poor (Table II), so that in most areas not only is drainage vertically downwards through the subsoil prevented, but drainage sideways must necessarily occur slowly. It has to be recognized, in any classification of these sites, that they are all united by the occurrence of impeded drainage in the subsoil and that a main and very important difference between them is the depth of freely drained soil which overlies this zone of impedance. On the basis of this, five types can be recognized in the groups into which Table I is divided.

There are (*a*) the moderately deep loam on Windy Hill; (*b*) the shallow clay at Kyloe Woods (Old Wood 18); (*c*) the shallow valley peats and the meadow soils; (*d*) shallow hill peats; (*e*) deep hill peats.

Extensive survey would show that these groups grade into one another; but they do nevertheless represent different types in land usage. Thus (*a*) is essentially agricultural land and is never available for forestry unless for some reason it is difficult to use for agriculture; (*b*) is consistently relict to forestry or low-grade grazing; the types in (*c*) are often present in wet meadowland; (*d*) and (*e*) together cover wide areas of moorland on the Border hills. The occurrence of *Molinia caerulea* as a dominant in these two latter types is certainly to be regarded as the result of grazing and would not be maintained if the land reverted to forest. It may be doubted whether the deeper peats would ever bear naturally any other than a type of swamp woodland with the soil water-soaked in winter, but moderately dry in summer, at least on the surface.

The different grades of fertility in all the types of soil are largely related to the depth of drainable soil which overlies the ill-drained subsoil and to the degree of topographical drainage as providing means of carrying off water by surface run-off, or sideways through the easily draining surface soil layers. The importance of these three things—(1) depth of freely draining soil, (2) quality of topographical drainage, and (3) the lack of good drainage characteristics in the subsoil—in determining the type and profitableness of land usage on sites such as these can hardly be over-estimated. The grade of fertility, and related to this, liability for the occurrence of root-disease, is determined largely by these things. It can hardly be doubted that the widespread occurrence of *Molinia caerulea*, usually growing on peat on the Border hills, has been determined, under grazing, by these deficiencies in soil character, the shallowness of good soil and the intractable nature of the subsoil being the principal determining factors considering the prevailing climatic conditions.

THE GROWTH OF SITKA SPRUCE AND OTHER CONIFERS ON THESE SITES

All foresters will recognize that, with the exception of the deeper aspects of the Windy Hill loams, the situations and soils described are such as are ordinarily considered suited for the planting of spruce in modern British forestry practice, and that, considering its rate of growth, great potential volume production relative to the common spruce, and the relative ease with which it becomes established on sites dominated by *Molinia caerulea*, Sitka spruce is the species usually to be chosen. The lack of experience with this species as a mature crop necessarily means that this decision is based mainly on the qualities it has shown during the early years of growth. It is, however, characteristic of all plants, including trees, that they not only show a characteristic initial reaction in growth to any particular environment, but that the age at which decline in vigour of growth becomes critical is equally characteristic (3, 1). It is as important from the economic standpoint to be able to estimate with reasonable accuracy how a species will end as to know how it will begin. This problem of estimating the end is, of course, one of the critical problems in British forestry, in which the cultivation of exotics plays

so important a part. The best way to obtain information about this matter is to examine growth curves of trees of the species it is desired to plant, and this the plantings in Kyloe and around Canonbie enable one to do up to a greater age than is possible in most parts of the country.

The most suitable growth curve for this purpose is that which shows the relationship between annual height growth and age. Fortunately in conifers, and in particular in the case of Sitka spruce, it is usually possible to measure past annual growths for a considerable distance back down the main stem. A selection of curves from data collected in this way in Kyloe Woods, Archer Beck Wood, and Moorburnhead Plantation are shown in Fig. 1. The data presented show that there was a fairly long initial period during which growth was slow; the growth rate then rose fairly steeply and for the next 15 to 25 years shows a marked periodic rise and fall, the length of the period from one low point to another varying from 3 to 6 years. Then a sharp and, on the whole, consistent decline in growth rate set in, in most cases, and there is every reason to believe that there is no recovery from this. The examples from Moorburnhead Plantation were taken from the more elevated and poorer part and faster growth rates are to be observed in the lower and usually more fertile situations. The greatest annual growth recorded was in Archer Beck Wood and was 73 inches.

The growth of Sitka spruce on moderately shallow fertile peat is illustrated by curves *A* and *B* which represent trees taken from Kyloe Woods and Archer Beck Wood respectively. Their crowns appeared dense, viewed from beneath, but from the side they were obviously thin at the top. The roots were severely diseased and, in the case of *A*, which had been overturned by wind, and with similar trees on the site of *B*, examination showed that dead large roots occurred within the well-drained upper layers of peat as well as over the surface of the underlying compact, ill-drained, mineral soil.

Curve *C* represents a tree which grew at Archer Beck on shallow peat. This tree had not been suppressed and was typical of many trees in the part of this wood in which the death of Sitka spruce was taking place. The soil profile is shown diagrammatically in profile 6, Fig. 2. Comparison with curve *B*, from the same wood, shows that the period of slow early growth was longer on this more shallow peat, indicating more severe competition on the part of the field layer, within the shallow rootable depth of soil. The rate of growth during the principal period of development in height was as great, however, though the length of this period was much shorter. The indications are that this was caused by the more limited supply quantitatively, though not qualitatively, within the shallow rooting depth. Most of the root system of this tree was dead. The recovery in growth rate, in the last years before wind-throw, was correlated with the growth of new roots: some of these, however, had died back to an appreciable extent even within this limited period of recovery.

The curves *D* and *E* compare the growth of two Sitka spruce in the upper part of Moorburnhead Plantation on what was originally grass moor dominated by *Molinia caerulea*. *D* represents a tree which grew on shallow fertile peat (profile 8, Fig. 2) and *E* one which grew on high bog (profile 12, Fig. 2), only the surface of

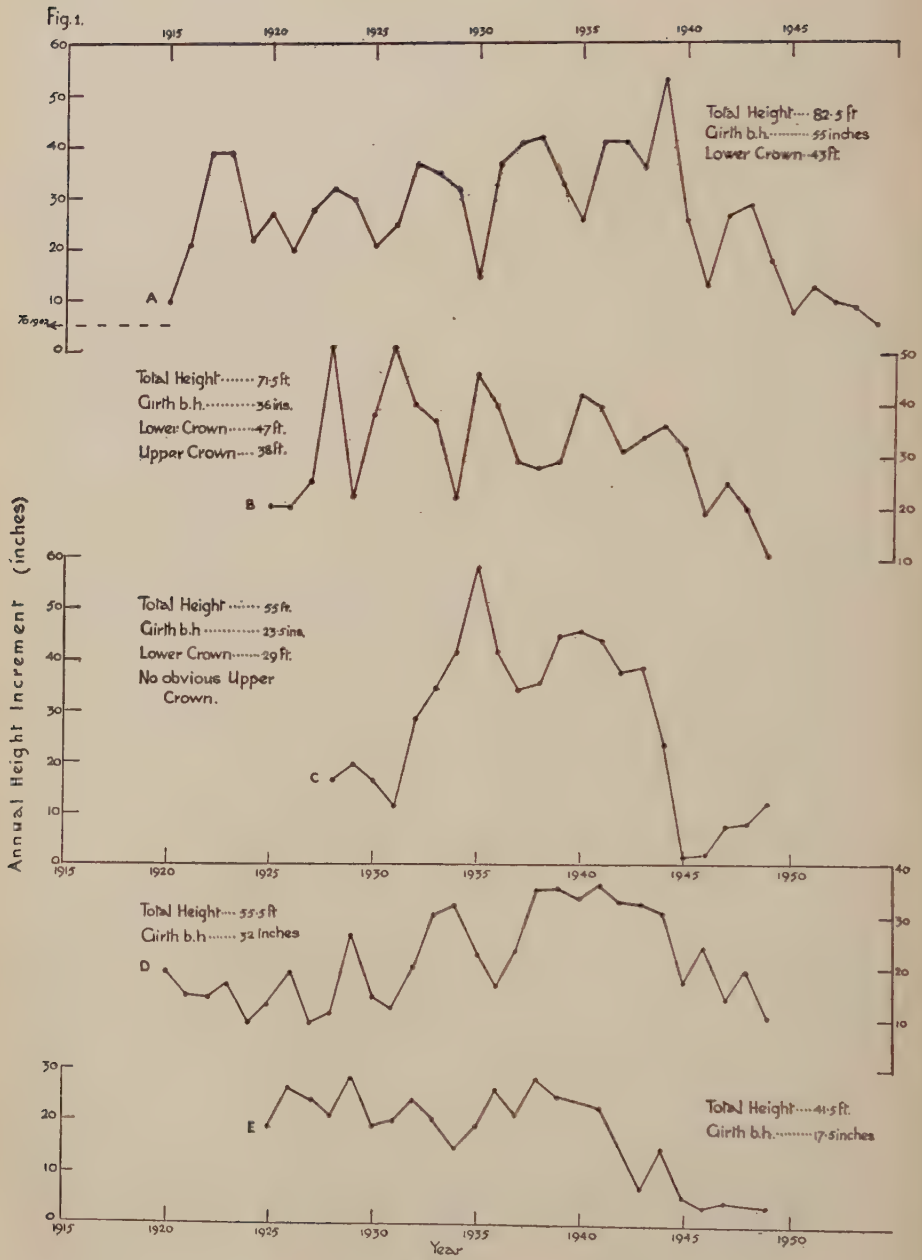
Fig. 1.
1915
1920
1925
1930
1935
1940
1945
1950
Total Height···· 82·5 ft
Girth b.h.····· 55 inches
Lower Crown··· 43 ft.
A
Total Height····· 71·5 ft.
Girth b.h.····· 36 ins.
Lower Crown····· 47 ft.
Upper Crown···· 38 ft.
B
Total Height····· 55 ft.
Girth b.h ····· 23·5 ins.
Lower Crown····· 29 ft.
No obvious Upper Crown.
C
Total Height···· 55·5 ft
Girth b.h····· 32 inches
D
Total Height···· 41·5 ft.
Girth b.h····· 17·5 inches
E
Annual Height Increment (inches)
Year

FIG. 1.

which was aerated sufficiently to make possible healthy root development. Tree *E* was nearly dead, but *D* was in comparatively good condition, though an appreciable proportion of its root system had died. The lower maximum rate of growth in these trees as compared with *A*, *B*, and *C* is largely to be accounted for by the considerably greater elevation of the site on which they grew, the shorter growing season and lower temperatures related to this, and the greater degree of exposure. Apart from this, the growth of *D* is essentially similar to that of *B* and is typical of trees the crown of which still appears to be in moderately good condition, though beginning inevitably to fail owing to the unavoidable limitations in supply for the sites concerned. This limitation of supply had already become acute in the site on which *E* grew, as is indicated by its final low rate of increase in height and was shown by its poor condition.

Growth curves for Norway spruce, Douglas fir (*Pseudotsuga taxifolia* Brit.), and Grand fir (*Abies grandis* Lindl.), which grew on soils with similarly limited conditions of supply for the needs of the roots, showed the same characteristics as those for Sitka spruce; but it was obvious from a comparison of Norway spruce some of which grew on peat and some on mineral soil, both being shallowly rooted, that the degree of drop in growth rate and of thinning and general debility in the crown depended largely on the extent to which the larger roots had died. If, as on the mineral soil in this case, death was confined mainly to fine roots, easily regenerated and within only the lower part of the shallow rooting-space, growth became retarded, but not to a catastrophic extent.

The following points may be made regarding these growth curves. Firstly, they depart from what may be expected in a healthily developing tree (*a*) in general shape; (*b*) in the very appreciable periodic variations in growth rate which occur during the principal period of height increment; (*c*) in the duration of this period which, for a tree of the growth capacity of a Sitka spruce, should be much greater than any of the examples show, especially for the growth rates indicated; (*d*) in the marked decline in growth rate, which is shown especially by curves *A*, *C*, and *E* when the trees are still quite young and small, considering the size and age to which this species can grow.

Secondly, these faults, and especially the onset of acute decline in growth rate, are exhibited by other species as well as Sitka spruce; e.g. Douglas fir, Norway spruce, and Grand fir. Inspection showed that all these species, so affected, had severely diseased root systems. The fact that these varied species were affected similarly points to similar and edaphic factors affecting all of them.

Thirdly, it cannot be said that the defoliating parasite, *Neomyzaphis abietina*, is the cause of the decline in Sitka spruce, partly because many of these showed no sign of present, or recent, severe infestation and still more because species which are affected slightly, or not at all, by this insect showed similar symptoms of decline in growth. Also bark beetles are not responsible, because decline sets in before they infest the trees.

SOIL CONDITIONS AS THE FUNDAMENTAL CAUSE OF DISEASE, INCLUDING EARLY DECLINE IN CONDITION

The conclusion that the principal adverse factors affecting the Sitka spruce are to be found in the character of the soil on which they grow warrants some further consideration. The data presented in Fig. 2 and Table II illustrate this.

The study of root systems on these soils indicates that the factors of fundamental importance in determining their value for the growth of trees are those which determine the amount and the regularity of the supply of water and air. It has to be remembered in this connexion that when a tree is small it requires only a

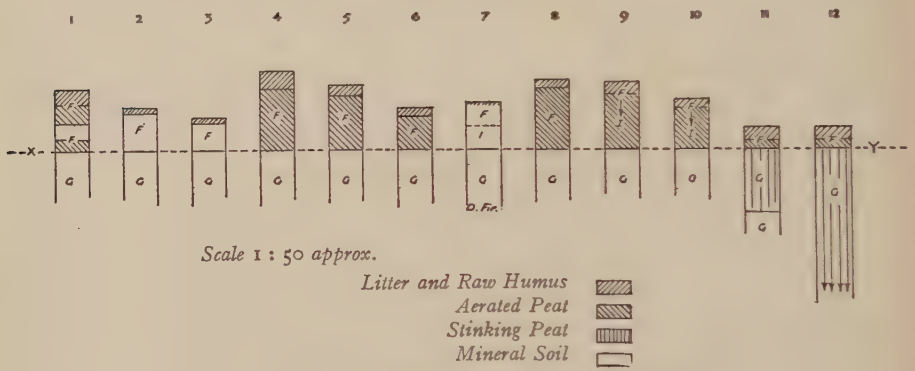

Fig. 2. Drainage Conditions in Soil Profiles (see Table II).

small supply, but that when it is large the supply must relatively be great. It is accordingly possible to grow a small tree successfully on a soil which is quite incapable of supporting a larger one. Now it is plain from Fig. 2 that all the soils illustrated are shallow in terms of the depth through which they are freely (*F*) or imperfectly (*I*) drained, and so of the depth through which they are adequately aerated. This depth is, at its greatest, so shallow that it is inadequate for the supply of a large tree, especially when the irregularities in supply are taken into account which arise owing to the occurrence of markedly dry or wet seasons. It is therefore necessary for the trees, especially as they become larger, to root within the zone of impeded drainage (*G*) if supply is to be maintained in dry seasons: even greater room for sideways spread does not compensate adequately for lack of rooting depth on these shallow soils.

Now there is abundant evidence in all the soils represented that roots descend into the impeded layer during the drier time of the year (probably between June and October). There is equally abundant evidence that most of these roots die within 12 months of their development and that, even on the sites with the better subsoils (e.g. profile 3, with a well-fissured clay), the roots within the impeded zone die within a few years. The line *XY* in the diagram thus represents a zone at which roots die, sooner or later, with the result that the part of the root system on which the tree has permanently to rely necessarily must develop within the shallow, and sometimes extremely shallow, drainable soil above. One has thus to

TABLE II. *Data relating to Sitka spruce (see Fig. 2)*

Profile number	*Site*	*Age*	*Main live rooting zone**		*Soil below main live rooting zone†*	*Topographical drainage*	*Crown density*	*Root die-back*	*Total height (ft.)*	*Av. diam. b.h. (in.)*	*Av. lower crown height (ft.)*
			Depth (in.)	*Type*							
1	Kyloe Woods	48	14·5	Peat	Sand and clay	Mod. poor	Thin tops	Severe	70–85	20·0	43
2	„ „	„	11	Loam	Clay	Very poor	Thin	Very severe	„	13·0	31
3	„ „	40	11	Heavy loam	„	Mod. good	Thin tops	Mod. severe	70–75	..	..
4	Archer Beck Plantation	35	23	Peat	Sand and clay	Mod. poor	„ „	„ „	65–75	13·5	44
5	„ „	„	17	„	Compact sand	„ „	„ „	Severe	„	12·0	43
6	„ „	„	12·5	„	Sand and clay	Poor	Very thin or dead	Very severe or dead	55	7·5	29
7	„ „	„	13	Sandy loam	„ „	Good	Thin tops	Severe	60–65	..	..
8	Moorburnhead Plantation	„	20·5	Peat	Sandy clay	„	Mod. dense	Mod. severe	50–55	10	26
9	„ „	„	13·5	„	Peat, then sandy clay	Mod. good	Thin or dead	Very severe or dead	„	..	..
10	„ „	„	4·5	„	„ „	Mod. poor	Thin	Very severe	40–45	..	..
11	„ „	„	6·5	„	„ „‡	Poor	Very thin or dead	Very severe or dead	„	4·5	25·5
12	„ „	„	6·5	„	Peat‡	Very poor	„ „	„ „	„	6·5	17

* Usually included an appreciable amount of dead root.
† Subsoil drainage was consistently highly impeded.
‡ The peat was anaerobic.

consider the problem of limitation of supply as determined by this type of rooting system.

Let the conditions be considered on the assumption that no cultural alleviation of the bad subsoil drainage is attempted. The growth curves indicate that up to the time when canopy is fully formed, usually about the time when the first steep rise in growth rate is ending, supply is probably adequate to maintain reasonable health (in terms of sound organs, not growth rate). Almost immediately afterwards the great fluctuations begin and these are an indication that, in the case of Sitka spruce especially, the amount of supply becomes periodically inadequate. This inadequacy is determined by a complex reaction based on, firstly, the killing of roots owing to waterlogging within the zone of impeded drainage and, secondly, owing to shortage of water, with the resulting death of roots, within the well-drained superficial layers of soil. The evidence for this is to be seen in the root systems themselves. They all, without exception in so far as examined, exhibited die-back of the horizontal runners on which the main root system within the freely draining zone is based and a corresponding but more severe die-back of heart-roots and sinker-roots on the surface of and within the impeded zone. Both types of die-back often result in a bunchy development of roots which is especially marked at the top of the impeded zone (along the line XY) and was very obvious, usually on root-plates of trees which were overturned by wind.

The difficulties of supply are thus twofold: there is the shortage of oxygen in the lower layers owing to excess water, and the shortage of water in the upper and drainable layers owing to their inadequate capacity considering the demands of a full canopy. The one aspect prevails during wet seasons, the other during dry, and they both result in a more or less severe dying back of the root. While the tree is still young the growth curves indicate that this type of root injury is overcome quickly; hence the rapidity with which a relatively good rate of growth is resumed at first after a severe check. Ability to make rapid recovery is, however, lost as the tree becomes larger; accumulated injury to the root then results in severe debility to the whole tree and the onset begins of the final decline from which there is no adequate recovery.

It is obvious that, according to this argument, the only way to avoid these pathological conditions arising is to increase the amount of supply and also reduce its irregularity. The main value of cultural treatment to the soil depends on the ability to do this. The subsidiary and less important value of such treatment is the reduction of the initial period of slow growth after planting. Now the only type of treatment which will be effective is one which will increase the volume of the drainable soil in which healthy root development is possible. There is only one way in which this is ordinarily attempted artificially; that is by draining, and in forestry one is confined to some type of ditch draining, which includes deep single-furrow ploughing as well as the older and hitherto more usual type of layout in draining. Such draining assumes that, firstly, excessive wetness is permanently or periodically a defect of the soil; secondly, if ditches are cut in adequate number and with appropriate layout and depth the excess water will be drained away at least from a part of the soil; and, thirdly, that when this has been done the water

reservoir in the soil during dry seasons will be adequate for the supply of the trees. All that can be done here is to bring forward evidence seen that drainage does or does not have these effects.

SUBSOIL DRAINAGE

(*a*) *Drainage of mineral soil*

There are two types of subsoil concerned here; the one is mineral as found in groups 1, 2, 3, and 4 (*a*), Table I, and the other peat, as found in group 4 (*b*). The mineral subsoils, which occur the more extensively and are associated with the more fertile soils, may be considered first. They can be divided according to the degree of structure possessed and, depending on this, the degree to which they break up on becoming dry. This is a matter of great importance, for upon it largely depends the possibility of draining a soil layer, the drainage of which is impeded and at the same time deepening the zone in which it is permanently well aerated. The subsoils concerned vary in texture from heavy clayey sands through sandy clays to material which has relatively a high clay content. Referring to Table I, the soil pits and also root-plates examined of wind-thrown trees in groups 2 and 3 (*a*) showed the presence of a well-fissured clay subsoil. The alluvium in Kyloe Old Wood 14 (group 3*a*) appeared to have the better structure, and if the area warranted the expense it certainly seemed that this might respond the better to draining. Naturally the situation is one in which adequate draining is very difficult. This is a site in which ordinarily there is a water-table. On the clay slope in Kyloe Wood 18 (group 2), however, there is no water-table, although free water may flow from the soil fissures during wet periods. The root-plates of wind-thrown trees provided abundant evidence that the subsoil fissures open as the soil becomes dry and that they then become occupied by tree roots. There can be doubt that under closed canopy of high forest of approaching 40 years of age, as during recent years this wind-blown area was, lack of water during dry seasons was at least as much a problem as excess during wet ones. It should be realized that in a subsoil of this type there is not necessarily any great quantity of water to be led away, for once the clay is full of water and its fissures closed, any further precipitation will drain over its surface through the shallow depth of surface soil of good structure. The effect of draining must therefore necessarily be limited, and observation of soils on sites of this type which, as in the case of Kyloe Old Wood, have been under forest for a very long time provides no evidence that it results in any really significant improvement of soil structure.

The sandy clay or clayey sand subsoils seem clearly to provide a still more difficult problem than the purer clays. Some have a fissured structure, but this is often obscure and appears not to be highly developed. Observation showed that in many cases roots penetrated these subsoils quite at random and without any evidence of passing down fissures. Even where fissure rooting was present, much random rooting through the soil occurred as well. Profile 7, Fig. 2, had been developed from material of this type. It was situated at the top of a steep slope with good topographical drainage and the site is old woodland; the previous crop, which consisted of oak, Scots pine, and Norway spruce, was felled in the First

World War. In spite of these advantages the depth of soil of good structure is shallow, and there was no indication that the penetration of the subsoil by tree roots had any permanent effect in improving its aeration and structure. Had there been any such effect it must have become obvious during the many years in which this site has been under forest.

There are thus indications that these sandy clays are to be regarded as intractable. Further evidence for this is seen where a tree stands on the edge of an open drain which is cut sufficiently deeply to expose the subsoil. There is a place in Kyloe Woods with an open drain about 6 feet deep. A Douglas fir stood near it so that the edge of the root-plate came to the edge of the drain. The tree was recently wind-thrown, and the root-plate showed the formations characteristic of development in a shallow ill-drained soil. Water stood in the shallow hollow made by the uprooting in spite of the drain being within a foot or so of one side of the hole. Examples were seen in Moorburnhead Plantation of Sitka spruce similarly situated beside drains which were cut moderately deeply and had been open and running for some time. Some trees had grown situated between two such drains, there still being room for the adequate development sideways of their root system. The subsoil was of this intractable type, and the root systems of the overthrown trees showed the typical shallow development together with death of roots. There seems, thus, to be no reasonable doubt that even fairly intensive ditch draining will not prevent root disease arising owing to adverse soil conditions. This is not to say that such drains may not be of advantage in aiding the draining of the shallow superficial soil layers and so promoting firmer and possibly slightly better root development.

(b) Drainage of peat

There will be no attempt here to discuss peat subsoils and their drainage except in so far as they were seen in the areas being reported on. It will be seen from the profiles represented in Fig. 2 that a gradation in drainable character is to be found in peat. The various aspects of this material may, however, be put into two groups for the purposes of this discussion. The peat above the XY line (Fig. 2) is more or less black in colour and possesses a structure which permits of the drainage of water through it (e.g. profile 8, Fig. 2). It is the characteristics of drainability and, as a consequence of this, aeration that make it a favourable rooting layer. The peat below the XY line (profiles 11 and 12, Fig. 2) was a warm, slightly reddish-brown[1] in colour, at least in part, and especially where this colour dominated, stank foully. This stinking material was fibrous, tough, and in contrast to the superficial drainable peat, did not fall to pieces when dug out, but remained consolidated. The root systems of the 35-year-old Sitka spruce which had grown on it showed that it provides a most unfavourable material for root development: their root-plates were in fact confined to the few inches of material shown above the XY line in the diagrams. The important question to be answered is, of course, will the cutting of drains so affect this material that it changes its nature and assumes the favourable structure which is associated with healthy root development?

[1] This colour turns to black on exposure to air.

Firstly, it is quite obvious from examination of the Sitka spruce that the mere growing of trees on this peat does not result in an increase in the depth of rootable soil; the consequence is merely the early onset of decline in growth and often death. All that results is in fact what may be called 'spruce swamp forest', in which, as the trees go into decline and die, the ground becomes recolonized with peat-forming grasses and mosses in which, indeed, natural regeneration may occur, but which if it develops can only reproduce the story of early decline and death. This type of development is well known on bad types of peat: in this case the fact that trees live for as long as 35 years and grow to a height of 40 or more feet (see Table II) suggests that the more important adverse factor is to be found in restriction of rooting space and not in nutrient supply per unit volume of rootable material.

The second point is that there is marked evidence that this bad peat does not respond in any favourable way to drainage. A small burn passes through the southern side of the big clearing recently made in the upper part of Moorburnhead Plantation. There are places in which it runs through a channel about $3\frac{1}{2}$ to 4 feet deep and where most of the bank is made of peat, although the burn itself runs through a channel cut in the underlying mineral soil. This peat is of the bad type. The burn has been running for many years and has been known to the local forester for the last 35. The depth of aerated peat is not more than 4 inches, either on the flat bank top or down its vertical or slightly overhanging sides. The peat within this shallow outer zone is a mass of fibrous, tough, stinking material and on it on either bank stand dead or dying Sitka spruce. This seems plainly to show that no ordinary drainage measure will result in the reclamation of this material and that its economic value as a soil for forestry is very limited, if indeed it has any except under conditions of free natural regeneration.

THE SOIL CONDITIONS WHICH FAVOUR WIND-THROW

The conditions favouring wind-throw have already been discussed in a previous paper (2), and no further detailed comment is needed here. The general evidence within the areas referred to above is that susceptibility to wind-throw is greatly increased by the shallow and usually defective root-development which occurs in shallow soils and that sites in which topographical drainage is poor and drainage vertically strongly impeded are particularly dangerous. Tall outstanding dominants with dense crowns are especially susceptible under these circumstances: but debilitated or dead trees with their open crowns are much less affected. Similarly, a deciduous habit, as in larch, reduces the danger of wind-throw in winter. The removal of excess water from these shallow soils aids the stability of the trees; but no appreciable reduction in susceptibility is to be expected unless rooting depth is greatly increased.

CONCLUSIONS AS TO THE CAUSES OF DECLINE IN CONDITION AND THE DEATH OF SITKA SPRUCE

The conclusion of this argument is inevitably that the main reason why Sitka spruce decline rapidly in growth rate, become thin-crowned and also die, is that the available rooting space is so restricted that considering especially the variations

in condition to which it is subject, deficiencies in supply either in air or in water must necessarily arise. The death of roots, the appearance of debility in the crown, and the eventual death of trees, is dependent on these things. Other factors such as low nutrient status of soil per unit volume, or defoliation owing to parasitic attack, would influence the trees adversely also, but their influence will be secondary to the underlying physical deficiency. If parasitic attack were the important adverse factor, decline and death would be appearing on the more favourable sites, as in the better parts of Windy Hill Plantation, and there is no evidence for this.

Observation shows that decline and, in some cases death, sets in when trees are of very different sizes; in one place relatively small, in others relatively large. It is, for example, quite obvious in Moorburnhead Plantation that trees have died where growth has been relatively good as well as where it has been poor. This problem should be thought of, not in terms of age of tree, but of the size of tree (see Table II) in relation to the capacity for supply of the soil on which it is growing. Sitka spruce is a tree with a great growth potential and it will, whenever conditions are favourable, show something of the fast, or long continued, rate of growth of which under good conditions it is capable. It is thus a commonplace that it will grow at a faster rate on a more suitable than on a less suitable site. This is illustrated by the growth curves in Fig. 1; the rate during the faster period of growth may be taken as indicative of site fertility: by this measure Archer Beck Wood has provided more fertile conditions than Kyloe Woods, while the sites sampled in Moorburnhead Plantation are the least fertile. The need of trees for volume capacity in rooting space under any particular soil conditions increases as they grow older, the rate of increase being especially fast at first. A tree on a site represented by curves *A* or *B* will thus increase its demand for soil volume much faster than one on sites such as are represented by curves *D* or *E*. It is only necessary to postulate that the site which promotes the faster growth rate has a strictly limited soil capacity for supply, and that this limited supply is well below the capacity needed for the full potential growth of the tree to express itself, to see that decline in growth rate and in condition of tree must set in at a pathologically early age. This is actually what has happened in Kyloe Woods and Archer Beck Wood. Sites such as those sampled in Moorburnhead Plantation, on which growth rates are slower and soil capacities more limited still, will by the same argument inevitably show decline after a pathological manner and at an early age; but because of the slower growth rate and so of rate of increase in demand, this age may be as great as that at which decline begins on the more fertile sites even though the supply capacity of the soil is more limited than on those. The age at which decline, or death, shows itself thus is determined by the rate of growth for the site and so the rate of increase in demand for supply capacity, in relation to the actual supply capacity of the site. As supply is a variable, depending on the varying soil conditions, the pathological events which cause decline to begin, or death to take place, will necessarily be related to periods of low supply; and as one is concerned here with, in the main, supply of water or oxygen, the danger periods will necessarily be related to unduly wet or dry seasons.

The relationship between the limitation in volume and in regularity of supply for the root and the onset of decline illustrates a general principle, namely, that in so far as soil conditions are concerned, the length of healthy life of a tree largely is determined by the rate of increase in its demand from the soil and the capacity of the soil to supply this demand. Judged by this principle it is plain that most of the soils examined in this report are capable of growing Sitka spruce as a healthy and reasonably vigorous tree only over a short rotation. Also, as compared with its growth on a soil which is able to satisfy its potential requirements, the size of tree will necessarily be small. Nevertheless, examination of the plantations at Kyloe and around Canonbie shows that on most of the soils a tree of usable size and, in the case of the better soils, one which reaches saw-timber size may be produced. Table II gives some idea of the relative sizes of tree produced in the plantations here investigated. This conclusion is naturally one of very great importance, but it follows inevitably from the evidence which has been brought forward and discussed above. It does, of course, need, and doubtless will receive, thorough investigation and confirmation in order that it may be known what the expectations in economic management really are on sites of the type investigated. It is not intended here to go further into this aspect of the matter, but it is the function of this discussion to bring out, as far as possible, what are the limitations of the various sites in terms of biological production, for it is these limitations which decide, biologically, the scope of management.

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A STUDY OF GROWTH RINGS IN TREES

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Part III. *The Relation of 'Lines' to Summer Weather*

SUMMARY

The frequency of 'lines' of denser wood within the annual ring in larch (*Larix decidua* Mill.) was compared with monthly records of rainfall and tables of droughts and rain-spells in the Bristol region. Moderate correlations were found with June rainfall (inverse), days in summer droughts, and a ratio giving a measure of the maximum dry-wet contrast between successive months from May to August. This 'contrast ratio' showed a high degree of parallel variation with 'line' frequency. A study of individual years suggested that the formation of a pronounced 'line' is associated with the occurrence of a spell of dry weather followed by a wet spell during the later part of the summer. 'Mid-lines' were found to be associated with a June drought breaking in July; late 'lines' with a dry-wet contrast in July or August, but in some trees these may be suppressed by the stoppage of growth. Vaguer 'lines' of lower frequency were associated in certain years with wet spells not preceded by noticeable drought. Individual 'lines' can thus be identified and roughly dated by some weather feature, so that their position sheds some light on the length of the growing season. It is suggested that 'lines' of denser wood may be occasioned by the killing or inactivating of mycorrhizal rootlets either by drought or by waterlogging, followed by partial recovery when the weather changes. This would accord with the theory that summer wood formation is normally associated with a developing water-deficit in the wood.

INTRODUCTION

DURING the course of the work described in Part II of this series (5) the writer was frequently asked how the 'line' pattern was related to weather conditions.

The literature of the attempt to establish such a relationship between tree-rings and meteorological records in a damp variable climate is not encouraging, and the heterogeneous nature of the data available in this instance made the prospect of success appear remote. Of the many factors involved in the general phrase 'weather conditions' the records only of rainfall are generally accessible in condensed and published form in the annual volume *British Rainfall* compiled by the British Rainfall Organization and published by H.M. Stationery Office. The task of compiling detailed daily records of other factors such as temperature into a form appropriate to the scattered localities in which grew the trees which had been studied was clearly impracticable.

A cursory comparison disclosed no obvious relationship between the frequency or prominence of the 'lines' and the type of growing season. The year 1918, for example, which had the highest 'line' frequency (96 per cent.), was memorable chiefly for its wet harvest, 1925 (86 per cent.) for a rainless June, but the record drought year of 1921 had only the average proportion of 'lines' (41 per cent.).

Most of the wet summers, however, had a low 'line' percentage, but the years 1917 (42 per cent.) and 1903 (73 per cent.) appeared to be exceptions.

The possibility had to be considered that the 'lines' might not be related to summer weather at all but perhaps to short-term changes in the spring affecting the cambium or to the delayed effect of conditions during the winter or the previous growing-season.

It was the 1908 ring with its two prominent, widely spaced 'lines' in the mid- and mid-late positions (see Part II, Pl. VIII, Figs. 1 and 2) which gave an indication that time would not be wasted on a closer comparison between the 'line' pattern and summer weather in the Bristol area. In the seasonal notes in *British Rainfall* for 1908 (p. 171) occurs the following sentence: 'The dry areas included . . . the south-west of England and Wales in the district of the two great summer droughts . . .', and in the notes for July we read: 'The lowest rainfall of England was in the south-west, where the great drought of July–August had its headquarters, and that of June–July had also been severe.'

APPLICATION OF THE RECORDS

The more the volumes of *British Rainfall* were studied the more the local character of the British climate impressed itself on the mind, and later work showed that the extent to which the two patterns, of wood and of weather during the growing season, could be related, depended largely on the accuracy with which the weather at the places where the trees were growing could be assessed.

The most detailed records which it was practicable to use were the monthly records at a small number of selected stations, often different stations in successive years, in the Bristol region or as near as possible to the sites of the trees, but it was clear that these gave a very rough picture of the weather-pattern at those sites. A succession of wet and dry spells, for instance, each about a month long, would be recorded as a series of months of average rainfall if the weather-change happened to occur in each case about the middle of the calendar month. Fortunately the seasonal and monthly notes, and the tables of droughts and rain spells, often provide evidence which runs across the monthly boundaries, and also, incidentally, of other factors besides rainfall, such as sunlight and temperature; so that, taking it all together, it was found possible to form a fairly clear, though broad, outline of the pattern of the summer weather in any particular season in the Somerset–Gloucester region, though it was obtained from very heterogeneous data and was difficult to present effectively in any quantitative form.

The records of no single station could be traced continuously through the series of years 1900 to 1940, but there was always a selection of records from a few stations within, or near to, the area (see sketch-map in Part II, Text-fig. 1). The matter was further complicated by the fact that the trees used in estimating the 'line' percentages were very irregularly distributed, viz. 37 from District I (N. Cotswolds), 26 from District II (Monmouth–Dean), 23 from District IV (west of Bristol), 8 from District VI (Hants), 7 from District III (W. Wilts.), and 4 from District V (W. Somerset).

The rainfall figures were therefore used in the following way: the amount recorded at the station in or nearest to District I was multiplied by 3, or sometimes a sum of three rainfalls was made up from two or three roughly equidistant stations; similarly, the rainfall used for Districts II and IV was multiplied by 2, and that used for the remaining three districts was added to the total without multiplication. The total was then divided by 10 to give an average 'weighted' roughly in proportion to the number of trees from each locality. In view of the small number of stations in the region recorded in *British Rainfall* greater accuracy was impracticable.

The stations used for District I were Cheltenham, Mickleton (Glos.), or Stow-on-the-Wold; for District II, Ross-on-Wye; for District III, Bath, Calne, Bradford-on-Avon, or Trowbridge; for District IV, Clifton, Long Ashton, or Bath; for District V, Angersleigh, Taunton, or Street; and for District VI, Stockbridge, Up Somborne, Basingstoke, or West Dean. For instance, the monthly rainfall estimated for the summer of 1935 was one-tenth of the sum of the amount recorded at Cheltenham $\times 3$, at Ross $\times 2$, at Long Ashton $\times 2$, at Bradford-on-Avon $\times 1$, at Taunton $\times 1$, and at Stockbridge (Hants) $\times 1$. In 1936 there was no record for Long Ashton or Bradford, so that the rainfall at Bath $\times 3$ had to do duty for Districts III and IV, and so on. The records are too bulky for publication, but the approximate monthly values so estimated are given diagrammatically in Text-fig. 3.

SUMMER RAINFALL

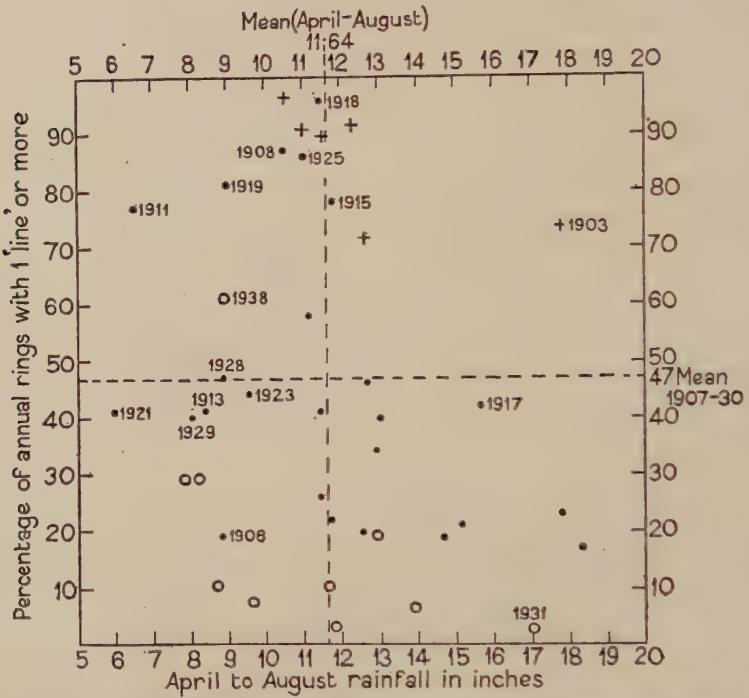
This rough relating of the rainfall stations to the distribution of the trees immediately revealed a tendency to inverse relationship between summer rainfall and 'line' frequency. Text-fig. 1 shows April-to-August rainfall totals plotted against percentage of annual rings with 'lines' for the years 1900 to 1940. As explained in Part II, the 'line' frequency for the first few years of the century is inflated owing to the youth of the trees, and depressed owing to the suppression of rings in the years after 1930. The years 1900 to 1905 have therefore been distinguished by crosses, and the years 1931–40 by circles, and the diagram makes it clear that these years do not fit well into the main distribution, but that, nevertheless, each series taken separately shows the same general tendency.

The inverse correlation is not high, and some of the highest 'line' values are grouped about the average rainfall, but if attention is limited to the central series (1906–30) represented by the black dots, the absence of high 'line' frequencies in wet summers is remarkable.

When the rainfall for each month of the growing season is plotted separately against 'line' percentage, that of June stands out alone as having a moderately high negative correlation ($r = -0{\cdot}60$, P about 0·002, for the years 1907–30). None of the values of r for the rainfall of the other months approaches significance, though all are negative. The application of the product-moment formula even to the central series of years is of doubtful validity, but may be useful for comparisons.

Text-fig. 2 shows June rainfall (circles) and July rainfall (crosses) plotted against 'line' percentage for these years. It will be seen that for June the main departure

from a close reciprocal relationship consists of a group of years with dry Junes (three with dry Julys also) below and to the left of the diagonal, and with less than the average 'line' percentage. The deviations above and to the right of the diagonal are negligible. Of the six years with over 75 per cent. 'lines', four had a dry June and a wet July, a fifth (1908) had over twice as much rain in July as in June, though both were on the dry side, and the sixth (1911) had average June rainfall, but an almost rainless July. The July rainfall, though on the average



TEXT-FIG. 1. Frequency of 'lines'/summer rainfall; correlation diagram. Black dots, 1906–30. Circles, 1931–40. Crosses, 1900–5. In the years 1931 to 1940 the number of 'lines' was reduced by suppression, and in 1900 to 1905 it was increased by the extreme youth of most of the trees.

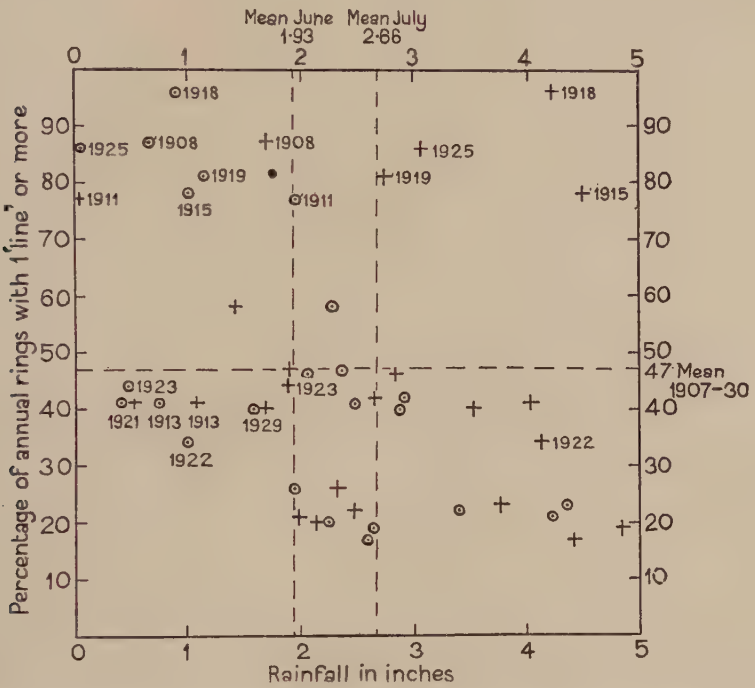
higher than that of June (2·66 inches against 1·93 inches) follows the same general reciprocal trend until the years of highest 'line' frequency are reached, and there it departs completely on the excess side in a manner not shown by the rainfall of any other month.

The suggestion therefore seems to be that the formation of a pronounced 'line' is associated not exclusively with drought but with the occurrence of a spell of dry weather followed by a wet spell, frequently, but not invariably, during the months of June and July.

DROUGHTS, 'RAIN-SPELLS', AND THE DRY-WET CONTRAST

Table I shows the totals, for each of the months April to August during the years 1910 to 1930, of 'rainless days', days in 'absolute droughts', 'rain days', and

days in 'rain-spells', recorded at any one or more of five selected stations (Bath, Clifton, Mickleton, Ross, Angersleigh)—a choice made necessary by the lack of continuity of the records at any one station, and the very few stations for which these figures are published in *British Rainfall*. The monthly record of 'rain days' starts with the volume for 1910. A 'rain day' is defined as any day with measurable rain (0·01 inch or more), a 'rain-spell' being a period of 15 or more consecutive



TEXT-FIG. 2. Frequency of 'lines'/monthly rainfall, for June (circles) and July (crosses); correlation diagrams. 1907 to 1930.

'rain days', and an 'absolute drought' a period of 15 or more consecutive 'rainless days' (i.e. days with no measurable rain, less than 0·01 inch).

TABLE I. *Totals and Percentages for the 21 years, 1910–30*

	April	*May*	*June*	*July*	*August*	*April to August*
Rainless days	302	353	381	331	300	1667
Days in absolute droughts	57	49	155	122	36	419
Percentage of rainless days in droughts	18·9	13·9	40·7	36·9	12·0	25·1
Rain days	328	298	249	320	351	1546
Days in rain spells	24	44	39	83	48	238
Percentage of rain days in rain spells	7·3	14·8	15·7	25·9	13·7	15·4

There is a marked tendency for more settled dry periods of at least a fortnight to occur in June and July, and more rainy spells of similar length in July, than in the other months. But if one is thinking in terms of its effects upon tree growth, such 'settled' weather, in which the same conditions persist for long enough to have a visible effect upon growth and then change abruptly, must be regarded as relatively 'changeable' or 'contrasty'; whereas the 'unsettled' weather of the meteorologist, in which heat and cold, rain and sunshine, and other contrasted conditions alternate too rapidly for the tree to distinguish them in terms of wood formation, must be regarded as relatively 'equable'. For instance, at the two extremes, in 1918 ('line' frequency 96 per cent.) a long rain deficiency culminating in a June–July drought was followed by a 'rain-spell', with a belt of heavy rain across southern England, and one of the wettest autumns on record. In 1931 (2 per cent. 'lines') every month of the summer was reported as 'dull, unsettled'.

The irregular nature of the records of dry periods in the region greatly limits the accuracy of comparisons, but April-to-August 'drought days' (1907–30) gave a positive correlation with 'line' frequency ($r = 0{\cdot}62$, $P < 0{\cdot}001$) and when plotted showed a closer relationship to the 'line' frequency curve than did the curve for 'rainless days' ($r = 0{\cdot}49$, P only about 0·05).

The 'rain-spell' data, affecting only 9 years out of the 24, are too sparse either to plot or to handle statistically, but it was noticed that in certain years, conspicuous on the 'drought' curve as having a high 'line' frequency in relation to 'drought days', 'rain-spells' occurred during the summer (e.g. 1927, 1915, 1908, 1918). In 1927, with 40 per cent. 'lines', there were two 'rain-spells' and no dry spell after April. On the other hand, the excessively droughty summer of 1921 shows a marked deficiency in 'lines'.

An attempt was made to work out a ratio which would give some measure of the dry-wet contrast in the weather. The most practicable figures were found to be the number of 'rain days' per month, the 'contrast ratio' being the highest ratio found between the number of 'rain days' in one of the months June, July, or August and the number in the preceding month (the May/April ratio not being the highest in any year). This gave a value of r of 0·64 (P about 0·002) with 'line' frequency, but it was clear that the monthly records often greatly reduced the contrast, e.g. when a dry spell ran over into the rainier month, and that they did so in such a way as to reduce the correlation with 'line' frequency.

CO-VARIATION

Correlations of the order of 0·6 have frequently been found in tree-ring studies, usually between annual rainfall and ring-width. Those found here, between one feature of the growth ring and the weather at one season of the year, are somewhat more useful, but it is clear that the crudity of the data available must remove the possibility of high correlations or of significant differences, e.g. between the effects of drought and 'contrast'. In any case, as mentioned in Part I (4), Glock (6) and others have criticized the use of the Pearsonian methods of correlation for continuous time series, in which the observations cannot be shown to be randomly distributed.

Glock favours the use of a 'trend coefficient' ($\mathcal{T}$)[1] which gives a simple measure of parallel variation. When 'line' frequency, in chronological order of years, is plotted against the weather data the extent of parallel, or reciprocal, variation is very striking. April-to-August rainfall ($r = -0{\cdot}47$) gives $\mathcal{T} = -0{\cdot}93$; 'drought days' for the same months ($r = 0{\cdot}62$) $\mathcal{T} = 0{\cdot}91$; 'contrast ratio' ($r = 0{\cdot}64$) $\mathcal{T} = 0{\cdot}98$ for the years 1910 to 1930. In these 21 years, giving 20 trend-comparisons, the 'contrast ratio' showed 17 parallel trends with 'line' frequency, and 3 opposite, all of small amplitude. But one of these last could be eliminated on inspection as being an artificial product of the monthly record which cut across a long drought (17 July–11 August 1917). This left two cases only of opposite trend, that is, 10 per cent.; and both of these were caused by a wet June (1912 and 1927) giving a high June/May ratio. Huber (8) has made extensive use of the percentage of opposite trends (*Gegenläufigkeit*) in cross-identifying ring-width series. Assuming random agreement only between the two series, the theoretical percentage will be 50, with a standard deviation $50/\sqrt{a}$, where a is the number of 'trends' compared. In this case, therefore, $\sigma = 50/\sqrt{20} = 11{\cdot}2$.

The numerical evidence cannot usefully be taken further. It is suggestive rather than conclusive, but gives a good indication of an inverse relation between June rainfall and 'line' frequency, and a direct relation between 'lines' and summer droughts, and a summer dry-wet contrast. The suspected relationship between some 'lines' and wet spells cannot be tested statistically, and for more detailed information a consideration and comparison of individual growing seasons becomes necessary.

POSITION OF THE 'LINE'

The 'line' frequency which has hitherto been used has been the percentage of rings examined which show one or more 'lines'. The identity of individual 'lines' was not at first realized, and the concept of a 'locus' or typical position of the 'line' within the annual increment did not emerge until a good number of examples were available.

Further study has shown that the 'locus' of a mid-line may have a range of as much as a third of the annual increment, whereas that of a late 'line' has a smaller range. The wide range of 'locus' is especially characteristic of certain years, e.g. 1915 and 1922. Although no single 'line' has been found to occur regularly in the 'early' position, a 'mid-line' is sometimes found there when the spring growth has been suppressed (see Part II, Text-fig. 5), and sometimes the suppression eliminates the 'line' altogether (Part II, Pl. VI. 2, 1915). In 1915 the records show a dry March and April, moderate but patchy rain in May, followed by a May–June drought ending about 22 June—in 1922, on the other hand, a cold wet April followed by a May–June drought. Both these conditions might explain the reduced, but variable, amount of spring wood formed before the 'line'.

[1] This is the ratio between the algebraic sum of xy and the total sum of xy regardless of sign, where x and y are the successive departures from the previous value in the two time-series being compared. Glock refers to this coefficient as 't', but the capital $\mathcal{T}$ used here avoids confusion with the t used in tests of significance.

At the other end of the season it is clear that in some trees the earlier cessation of growth eliminates the late 'line' which is found in others, often in dominants growing beside them. It is significant that none of the highest 'line' values is found for late 'lines', although some of them are for mid-late 'lines'. The cluster of 5 years (1913, 1921, 1923, 1928, 1929) with about 40 per cent. 'lines' which form a conspicuous group on the left of the 'scatter' diagram (Text-fig. 1) are all years with late 'lines'.

Although 'lines' were recorded in five positions it was not found possible to arrange them in strict order of position within the ring, but only to place them in three groups, 'mid', 'mid-late', and 'late', with a rough estimate of their relative order within the groups which have entirely arbitrary limits. The 1922 'line' alone was regarded as, on the average, 'mid-early'. Table II (below) shows this grouped arrangement, the 'lines' being designated in the first column by the year; and where two or three 'lines' occur in a single annual ring the figures (1), (2), or (3) indicate their order of formation. The dates of the ending of dry weather and the beginning of 'rain-spells' are also given for comparison.

TABLE II

Average position of 'lines'	*End of absolute drought*	*End of partial drought or dry spell*	*Beginning of 'rain-spell'*
Mid-			
1922	11 June	23 June	22 June
1915	23 June	24 June	19 July
1938	21 April	11 May	..
1927 (1)	..	1 May	16 June
1914	1 May	..	..
1930	18 June	22 June	..
1917 (1)	8 May	..	28 June (rainstorm)
1911 (1)	15 June	17 June	..
1908 (1)	6 July	7 July	..
Mid-late			
1918	8 July	..	9 July
1919 (1)	3 June	22 June	..
1908 (2)	9 August	21 August	21 August
1925 (1 and 2)	1 July	21 July	..
Late			
1928	25 July	26 July	..
1929	20 July	..	..
1923 (1 and 2)	12 July	27 July	..
1911 (2)	25 July	..	..
1919 (2)	..	15 August	..
1927 (2)	..	..	6 August
1921	13 July	1 August	..
1913	8 August	..	..
1916	11 August	..	..
1911 (3)	23 August	..	..

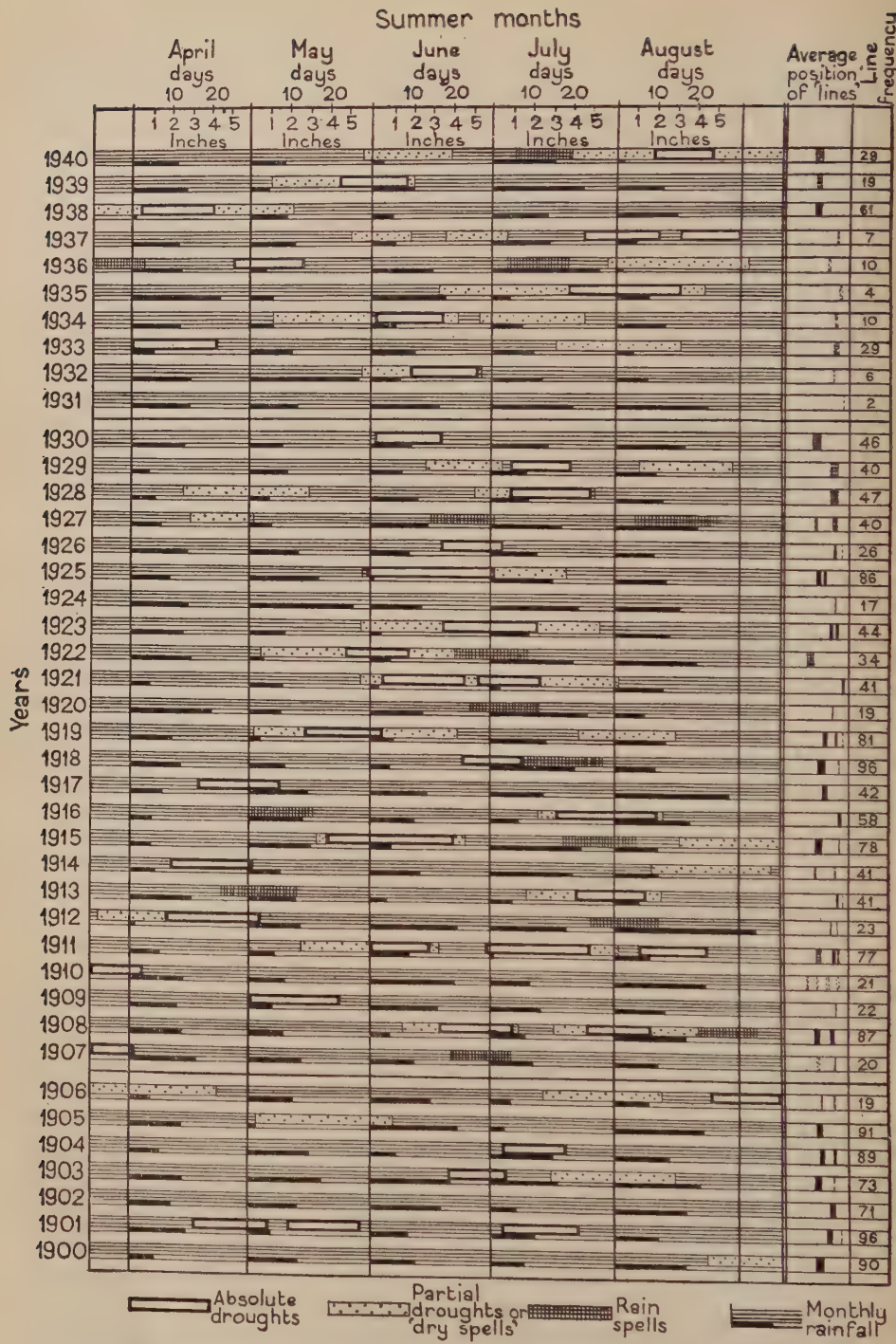
The assessment of the position of these 'lines' was made before the weather records had been seen, and particular doubt was felt about 1919, in which the two 'lines' were not always distinguished; but there is a clear indication that the position of the 'line' corresponds broadly with that of the 'point of contrast', the change from drier to wetter weather, in the growing season, and that late 'lines' are associated with such a change in August or July, and 'mid-lines' with one in early July, June, or earlier. The correspondence is more consistent in the case of late 'lines' than the others.

But droughts ending before June do not seem to be associated with earlier 'lines' than those ending in June or even early July (1918 occasionally has early 'lines'; see Part II, Pl. IX. 1), and it may be doubted whether a direct relationship holds for the months of April and May. The evidence favours the view that the effect of spring droughts is to intensify the effect of a midsummer contrast in producing a 'line'. Where June was wetter than July there are few and faint 'lines' even when there is a pronounced April or May drought-rain contrast which, if it had occurred later, would have been associated with a firm 'line' (e.g. 1906, 1909, 1912). On the other hand, in 1914 there was a moderate mid-season contrast —June, 2·46 inches, 10 rain days; July, 4·04 inches, 21 rain days—with nothing approaching a June drought to account for a 'mid-line' of 41 per cent. frequency, but an absolute drought from 11 April to 1 May. In 1938 there was again no formal drought in June, which was, however, rather dry (1·04 inches, 16 rain days) followed by 2·81 inches in July, scarcely enough contrast to account for the marked 'mid-line' of 61 per cent. frequency, but there was a record partial drought of 72 days, from 1 March to 11 May, with an almost rainless April (0·1 inch). In 1918, the year of the most prominent 'line' (96 per cent.), not only was a short June–July drought followed immediately by a 'rain-spell' but, as *British Rainfall* remarks in its monthly notes (p. 63): 'Of the dry months of the year, four, from March to June inclusive, were consecutive, and, apart from a wet September, this period of deficient rainfall constituted the principal feature of the year.'

'LINES' AND DROUGHTS

So far as is possible on one page, Text-fig. 3 presents the available data on the two patterns, of weather and of 'lines', in a comparable form. The multiple 'line' years 1908, 1911, 1919, 1925, 1927 are worthy of particular attention.

The wide spacing of the two prominent 'lines' in 1908 made it possible to distinguish them clearly and to relate them to the two summer droughts in the south-west, of June–July and July–August respectively, the latter being followed by a 'rain-spell' which may account for the distinct separation of such a late 'line' from the 'autumn band'. In the dry summer of 1911 there were three droughts, in May/June, July, and August, the second being the most severe, but generally there is only one 'line', in the mid- or mid-late position, corresponding to the end of the June drought. The ring has the appearance typical of a dry summer; it is rather narrow, with a thin 'hard' 'autumn band' which sometimes appears double owing to the presence of a very late, thin, 'hard' 'line'; but at four sites near the Bristol Channel, in larch, Douglas fir (*Pseudotsuga taxifolia* Brit.), and Norway



TEXT-FIG. 3. Diagrammatic summary of rainfall data in the Bristol region for the years 1900 to 1940, in relation to the 'line' pattern in larch butts. This pattern is considered to be typically presented only in the years 1907 to 1930, but since these limits are arbitrary the whole of the data is included.

spruce (*Picea abies* Karst.), all three 'lines' were found corresponding to the three droughts (see Part II, Pl. VII. 5). It is now clear that what is characteristic of these sites is not the occurrence of local 'line'-forming factors, but the continuance of growth in 1911 long enough to allow the weather pattern to record itself in the wood. At most sites, evidently, the severe July drought brought growth to a stop after a few small, dense tracheids had been formed; but in some trees the early August rain carried on growth until the August drought stopped it with a similar 'hard' band, so that the earlier dense zone became a very late 'line', giving the effect of a double ending to the year's growth. At the sites mentioned above, however, growth must have gone on well into September, as judged by the separation of the third 'line' from the final 'autumn band' with which growth in these trees stopped for the season.

The similarity between the thin, 'hard', often double, 'autumn bands' of the two dry seasons 1911 and 1921 is striking; and the same features are present, though 'softer' and less 'droughty', in the years 1913, 1916, and 1923, all with July or July–August droughts which seem to have stopped growth in some trees, and formed a late 'line' in others. The 1923 ring is unusual in often having two very close late 'lines' within the 'autumn band'; and in 1925 a similar feature occurs more prominently and in an earlier position, corresponding to an earlier drought (a record rainless June). There is no obvious explanation of these double 'lines', but in both years the drought broke in thundery weather with patchy rainfall.

'LINES' AND WET WEATHER

Evidence for the suspected relationship between some 'lines' and wet spells is to be seen only in a few seasons. In 1927 there were no summer droughts, though April and May were rather dry, with a 'dry spell' at Ross in April, but the two 'lines' correspond in position to the two 'rain-spells'. Most of the 'lines' associated with wet weather not preceded by drought are rather vague and of low frequency. In 1910, for instance, there is sometimes a succession of faint, vague zones of denser wood, and this corresponds to a wet summer with a succession of depressions crossing the British Isles. In the wet summer of 1920 there is sometimes found a mid-late 'line' (19 per cent.) corresponding in position to a July 'rain-spell'; and in 1917 an occasional mid- to mid-late 'line' seems to correspond to the great rain storm of 28 June, when a record fall of over 9 inches occurred in parts of Somerset. It is at least certain that a drought is not necessary for all 'line' formation, and some support is given to the hypothesis that it is the dry-wet contrast, and not merely the drought, which is responsible for the more prominent 'lines'.

DISCUSSION AND CONCLUSIONS

The formation of summer wood is unlikely to prove a simple phenomenon, and the effects, in particular, of temperature and sunlight and the exhaustion and accumulation of food reserves, are not distinguishable from those of dry and wet weather with which they must show parallel variation, but there is strong circumstantial evidence that soil moisture conditions can be a critical factor.

Chalk (2) found his highest correlations between spring-wood volume in Douglas fir and May–June mean temperature, but between summer-wood volume and June–July–August rainfall, and more recently he has produced further evidence pointing to a relationship between summer-wood area and June–July rainfall (Chalk (3)). This accords well with the general observations on the ring-pattern, the absence of 'lines' corresponding to spring droughts or 'rain-spells', and the 'hard' thin character of both 'line' and 'autumn band' in a droughty summer as compared with their broader and softer character in a wet summer.

Priestley's theory (9) that when extension growth ceases the products of photosynthesis accumulate and a water deficit develops in the wood, and that this process probably coincides with the formation of summer wood, is not, at first glance, supported by the association of summer wood with rainfall and of certain 'lines' with wet weather. The appearance of the drought-year rings, especially 1911 and 1921, shows that prolonged drought does not induce a gradual onset of summer-wood formation as the water deficit increases but, if sufficiently severe, brings growth to a sudden halt after the formation of a few tracheids of reduced size. Priestley's suggestion was that, in Dicotyledons, cambial growth was stopped by the displacement of water by air in the intercellular spaces of the rays, but in conifers, with their smaller ray-spaces, he expected to find cambial activity more independent of water-supply. The evidence here presented does not support this air-space theory as applied to conifers, to which, indeed, Priestley had realized that it probably did not apply; and the suppression of late 'lines' in many trees, or rather their transformation into 'autumn bands', in drought years, shows that growth is readily stopped by drought conditions in the later part of the summer.

The fact that the more prominent and frequent 'lines' are associated with relatively heavy late-summer rainfall following a rain deficiency, taken in conjunction with the occasional fainter 'lines' associated with wet weather not preceded by any noticeable drought, makes it appear very probable that the later part of the 'line', as well as the less dense tissue which follows and delimits it, is formed after the rain comes.

The only explanation occurring to the writer which seems to fit the facts refers to the effect of soil moisture conditions on the absorbing organs of the tree. Zones of dead, or dry and inactive, mycorrhizal rootlets were frequently seen in the soil pits during the Universities' Survey, especially during the dry autumn of 1940, and the Oxford parties drew particular attention in the report to the effects of drought and of waterlogging in causing the death of roots especially in certain horizons. Glock (7) points out that in trees growing with excessive water-supply the response to increase in soil moisture is inverse, and it is likely that 'lines' associated with 'rain-spells' in wet summers are examples of such a response.

Any substantial reduction in the absorbing area of the root system at a time when transpiration is at a maximum and photosynthesis is actively proceeding and its products are accumulating in the tree might be expected to produce a thicker wall and a smaller lumen in the tracheids unless or until it is sufficiently severe to bring growth to a stop. The amelioration of either drought or water-

logging in the soil, resulting in the recovery of inactive rootlets and perhaps the formation of new ones, might be expected partially to reverse the process if it has not gone too far, or if it is not too late in the season. Viewed in this way, the fact that 'lines' of summer wood are found to be related to weather conditions during June, July, and August likely to cause a temporary check to the root system, gives support to the theory that the onset of summer wood is normally connected with a developing water deficit in the wood.

The absence of 'lines' in the spring wood corresponding to spring droughts may be related to the level of food reserves in relation to growth demands, as well as to the relatively high winter water-table; but this last would not account for the absence of 'waterlogging lines' in a wet spring such as that of 1924. The conditions for summer-wood formation evidently do not exist in the tree in the spring, whatever the external circumstances. The initiation of growth in the spring appears to be mainly a photoperiodic effect, and the work of Wareing (10) has already shown that different species of trees differ in the relation between their apical and cambial growth, probably in accordance with differences in their auxin metabolism. The problem of spring-wood formation is certainly more complex than that of summer-wood formation, for the influences of the previous season and of the winter have also to be taken into account.

Wareing (11) has also shown that in *Pinus sylvestris* extension growth ceases in June, but cambial growth continues into October and is normally stopped by the short day-length, probably owing to reduced production or availability of auxin within the plant. In larch the facts are less fully known, but extension growth may continue into the autumn, especially in young trees, and cambial growth probably at least as long. There is often a lag of 4 to 5 weeks between changes in apical growth affecting the supply of auxin and the corresponding changes at the base of the trunk. As the trees age, growth tends to stop earlier, which accounts for the better presentation of 'lines' in the younger trees.

The 'line' pattern has thrown a little light on the duration of growth in larch and on its variation from tree to tree and, now that its relation to the weather is partly understood, it is capable of throwing more. In 1911, for instance, young larch, Douglas fir, and spruce at a few sites continued growth after forming three 'lines', the last of which can be related to a weather-change in late August, but in most of the trees examined from the Bristol region cambial growth at the base of the trunk did not survive the effects of the July drought, although one cannot say when these effects reached that part of the tree. In 1908 half the trunks examined had continued growth well after a late August weather-change, and in 1921, 41 per cent. of rather older trees had continued to grow after the long summer drought was broken by a little rain about the beginning of August. There are other 'lines' in trees of comparable age (1919(2) and 1927(2)) associated with a later weather-change (see Table II).

The relationship between weather and 'lines' in larch here put forward seems to hold good also for the few trunks of other conifers examined, but no attempt has been made to extend it to broad-leaved trees. A paper received from G. L. Amos (1), however, shows that in Australia *Eucalyptus gigantea* Hook. f. is capable

of forming, under severe drought conditions, a zone of abnormal parenchymatous tissue in the wood, quite clearly recognizable and serving as an identification feature for the ring.

In Part II of this study the main objective was the identification of the individual ring, but the relating of the more prominent 'lines' to a recognizable feature of the summer weather in many cases enables the individual 'line' within the ring to be identified. This greatly eases the task of ring-reading in districts where a pattern has not been established, by providing a 'clue' to the pattern in the form of a preliminary picture of the probable main 'line' features of any given year which can then be confirmed or modified as and when a sufficient number of tree-sections become available. Further, the establishment of the 'line' pattern for a particular season assists towards the distinguishing of the type of modification which may be introduced by local and pathological factors, especially as these usually affect the amount of wood formed at certain periods in the season, and the position of a recognized 'line' gives an indication of the amount of wood formed before and after the occurrence of the weather-feature by which it is 'dated'.

The limitations of the material and records available have been sufficiently stressed, but if further confirmation of these working conclusions is to be sought from felled timber a larger and more systematic collection of tree-sections, and more detailed weather records, will be required; and a parallel experimental study of young trees is highly desirable.

ACKNOWLEDGEMENT

Thanks are due to Mr. W. J. J. Neville for redrawing the text-figures.

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FACTORS AFFECTING THE GROWTH AND FORM OF YOUNG BEECH AT GARDINER FOREST, WILTSHIRE

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SUMMARY

The record of an intensive study of young beech (*Fagus sylvatica* L.) which had been introduced by planting into an area of old hazel (*Corylus avellana* L.) in 1946 using different sizes of strips and groups. One object was to find out which of the environmental factors, e.g. soil, root competition, light intensity, frost, wind, and humidity, were responsible for the very marked differences in growth. The same beech were also classified according to their form and their tendency to fork. The conclusions reached are enumerated at the end of the paper. Among the more important are that, up to this stage at any rate, the depth of soil over the chalk has no effect on growth; root competition with dense hazel is not injurious; even quite appreciable reductions in light intensities have no ill effect; hazel hedges provide considerable shelter from wind, which is likely to be of value where water is scarce, and the number of forks is closely related to leading shoot damage of which Lammas shoots are an important source.

DESCRIPTION OF THE SITE

WHEN Gardiner Forest came into the possession of the Forestry Commission just before the recent war it formed an area of nearly pure hazel coppice which had grown to a height of about 18 feet at an age of 30–40 years with very scattered and occasional standards of oak and ash on a thin but fertile soil overlying a chalk downland. In 1946 beech of a single origin was planted in a number of compartments at each of which the hazel coppice had been treated in a different way when preparing the ground for planting. After five growing seasons the development of the beech in some areas was so markedly different from that in others that a study was made to discover which site factors had affected the early growth and form of beech.

The study was made in Stonedown Wood, about 10 miles south-west of Salisbury. The rainfall is about 33 inches annually, and although the woodland lies between 350 and 700 feet above sea-level, it is not unduly exposed to the prevailing southerly and westerly winds. Unseasonable frosts are relatively infrequent.

The places where the beech were studied were:

1. *Part of Compartment 18.* Strips 13 feet wide running NNE.–SSW. were cut through the existing coppice leaving hedges 9 feet wide between adjacent strips. Beech had been planted at $4\frac{1}{2} \times 3$ feet in the cut strips. In one part of this site where hazel was absent and the dominant shrubs were dogwood (*Cornus*) and privet (*Ligustrum*) the beech were still in check after five growing seasons and had an average height of $1\frac{1}{2}$–2 feet, while nearby beech planted amongst hazel had a mean height of $5\frac{1}{2}$ feet and the best were as tall as 10 feet.

2. *Part of Compartment 21.* Irregular gaps about 30 feet across had been cut out of uniform hazel coppice and planted with beech at about 4×4 feet. The beech were vigorous, had a mean height of 6½ feet, but were much forked.

A smaller number of beech had been planted amongst the hazel hedges separating the gaps; the shade was quite dense, and although the trees had a finer branching habit their mean height was only 4½ feet.

3. *Part of Compartment 22.* Strips 10 feet wide running WNW.–ESE. leaving hedges 8 feet wide were planted with beech at 3×3 feet, their mean height having reached 5½ feet.

4. *Part of Compartment 23.* Irregular gaps about 20 feet across planted with beech at about 4½×4½ feet. The mean height was about 5½ feet, and the trees were of good form, only a small proportion being forked.

FACTORS PROBABLY AFFECTING THE HEIGHT GROWTH OF BEECH ON THIS SITE

It was thought, from first principles, that the following matters might be involved both in the very bad growth of beech in part of compartment 18 and in the good growth elsewhere with the various beneficial and adverse factors operating to different degrees in the various places.

1. Edaphic factors:
   - *a.* Soil depth
   - *b.* Soil moisture
   - *c.* Soil aeration
   - *d.* Soil temperature
   - *e.* Soil pH
   - *f.* Soil 'fertility'
2. Root competition.
3. Aerial factors:
   - *a.* Light intensity
   - *b.* Frost
   - *c.* Wind and humidity
4. Genetic variations between individual trees.

It must be emphasized that this study aimed at discovering how variations in these factors from place to place affected beech growth, not at making a fundamental study of the precise effects of each factor. Observations or measurements were, in fact, made on each site factor except soil aeration.

In order to throw some light on the actions of all these factors the first step was obviously to carry out a detailed examination of the beech crop and the vigour and species making up the coppice, shrub, and ground flora at each site. Accordingly this was done.

Probably the best way to show the results of this study will be to comment on each of the site factors mentioned above and to show how under different

circumstances they produced the observed variation in height growth and form of beech.

1. *Edaphic factors*

a. Soil depth. The depth of mineral soil overlying the chalk varies from 7 inches to over 24 inches with a mean of about 12 inches. About 300 soil pits were dug and, surprisingly enough, their evidence suggested very strongly that up to this stage of development and on this site the soil depth has no influence whatever on beech growth.

b. Soil moisture. Lying over the chalk the Gardiner soil is freely drained, and recent work seems to show that such soils are kept moist by rain and dew, but that the ground water contributes little or nothing to the surface layers.

Soil samples were taken from a number of places of both good and bad beech growth and the loss of water on air drying was determined. In general soils from sites where the ground flora was herbaceous amongst hazel coppice lost 25–30 per cent. water, while from places where dogwood, privet, and grass roots formed a dense surface mat the water losses were 20–25 per cent., and there is little doubt that this difference was due to the interception of rain and dew by surface-rooting species. The soil samples were of similar texture and their water losses are probably in the same ratio as the quantities of water available to the beech. The samples were taken early in June after a long dry spell, and as all the moisture figures were well above the wilting point for beech, it is unlikely that low soil moisture could be the primary cause of any important differences in beech growth.

c. Soil aeration. No observations were made on soil aeration, but the light texture of the soil indicates that normally it must be good. In the area of bad growth in compartment 18, however, air diffusing into the soil would have to pass through the dense mat of surface woody roots and in this process would be robbed of oxygen; the possibility of this effect being important has long been controversial, and without an analysis of the soil atmosphere it can only be said that if this factor is ever significant one would expect it to be so in compartment 18.

d. Soil temperature. Soil temperatures were recorded at 6 inches below the surface during a fine spell early in September and very little difference was found between the various sites, the highest temperature being 59·9° F., and the lowest 58·8° F. It is thought that such differences would not be very important.

e. Soil pH. The soil reaction varied from 7·8 to 8·2, but showed no correlation with beech development.

f. Soil fertility. This term represents the sum of a number of factors which are difficult to assess individually. Because it was not possible to have a chemical analysis made of soil samples and because a study of the ground flora and soil profiles failed to show any changes in soil fertility, it was decided to use the height–age curves of the hazel coppice to indicate the total affect of soil fertility in different places. A large number of hazel stems were cut and mean curves were drawn, and the mean heights when 25 years old at each site are shown in Table I below. It is thought that these figures give a fair comparison of hazel growth and that the

same factors which promote hazel growth would be favourable to beech, so that the heights shown should give a useful indication of the variation in soil fertility.

TABLE I. *Mean height of hazel coppice 25 years old*

Location	*Height in feet*
1. Compt. 18 north	19
2. Compt. 18 south	14½
3. Compt. 21	17¼
4. Compt. 22	17
5. Compt. 23	16

2. *Root competition*

On digging up a number of beech at random in the area of bad growth in compartment 18 it was found in every case that those trees still in check had developed scarcely any root system, and that what little root was present was almost wholly in one small ball of fibres completely enveloped by and entwined with the mat of vigorous privet and dogwood roots which dominated the surface 3 inches of the soil. It seems certain therefore that these trees had been planted so that their roots were enclosed by the already well-established woody roots which effectively prevented the development of beech roots by their overwhelming competition. This was borne out by the fact that when well-grown young beech were dug up from adjacent areas of good growth where the ground flora was herbaceous amongst hazel coppice, whose roots do not form a surface mat, the beech roots showed that they had originally been planted in a tight ball, but that they had successfully established well-developed root systems with feeding-roots in all the soil horizons. There were certain places, however, where the hedges between the strips were of hazel and the planted beech were growing vigorously in spite of the fact that the vegetation in the strips was dominated by vigorous dogwood with occasional privet which had produced their normal dense surface mat of roots. The problem was why in these cases the beech had developed in spite of woody weed competition.

A possible answer appeared to be that the beech had been planted into an hazel+herb association which was later invaded by dogwood and privet, and a count was made, therefore, in 300 places in compartment 18 of the age of the woody weed roots and the growth of some 3,700 of the beech. This established beyond all doubt that where the beech had been planted into an existing mat of woody weed roots they had scarcely grown at all in four seasons after planting; where woody weeds had invaded the site since planting the beech growth was slightly reduced, but where there were no woody weed roots beech growth had been vigorous. The mean height increments since planting in various parts of compartment 18 are shown in Table II below.

These figures suggest quite clearly that the existence of well-established roots of dogwood and privet at the time of planting beech are very injurious to the growth of that species while hazel roots appear to have no adverse effect at all.

TABLE II. *The relation between beech growth and presence of woody weeds (Height increments in inches since date of planting)*

	Mixed herbaceous and woody flora			*Woody weeds dominant*	
	Hazel and herbaceous flora	*Woody weeds younger than beech*	*Woody weeds older than beech*	*Woody weeds younger than beech*	*Woody weeds older than beech*
Mean of all beech .	31·2	26·4	15·1	25·8	10·1
Mean of best ⅓rd of beech	45·6	42·0	25·2	39·1	19·3

3. *Aerial factors*

a. Light intensity. The effect of light intensity on forking is considered later. Measurements of light intensity measured in foot-candles using a photo-electric cell were made under a variety of conditions, and the amount of light reaching each place was expressed as a percentage of the reading in full daylight in the nearest open area.

(i) *Effect on height growth.* It was noticed that in certain places such as the south side of all groups and the south side of strips which ran from east to west the beech crowns never received any direct sunlight because of the shade cast by the surrounding hazel, while on the north side of groups or in those strips running north to south the beech crowns received a great deal of direct sunlight during fine weather. The extent to which diffuse light on cloudy days was reduced within the groups and strips was also determined, and the results are shown in Table III below. The heights shown in column 4 are the means of 100–200 measurements at each location.

TABLE III. *Percentage of full daylight reaching various sites*

Location (1)	*Diffuse light in cloudy weather* (2)	*Direct sunlight* (3)	*Total height of beech in inches* (4)
1. Centre of groups . . .	75	Variable	. .
2. N. side of groups, compt. 21 . .	65	98	76·0
3. S. side of groups, compt. 21 . .	50	2–9 (shade)	78·5
4. In hazel hedge, compt. 21 . .	10–30	1–2 (shade)	51·9
5. N. side of groups, compt. 23 . .	65	98	64·2
6. S. side of groups, compt. 23 . .	50	2–9 (shade)	65·4
7. N.–S. strips, compt. 18 . .	90	98	66·7
8. E.–W. strips, compt. 22 . .	55	2–20 (shade)	66·1

Except for No. 4, these heights are considered very good for such young plants, and it appears therefore that up to this stage of development beech can maintain an excellent height increment without receiving any direct sunlight and that the intensity of diffuse light can be reduced to half without causing any loss of vigour,

but that if diffuse light is reduced to one-third or less the rate of height growth will diminish.

(ii) *Effect on stem diameter.* There is a strong visual impression that shaded young beech are more slender than those grown in full daylight, and measurements were taken to see whether this was so. The trees were grouped into 1-foot height classes and their diameters measured just above the butt swelling and at mid-height with callipers. A total of 200 trees were measured in the east to west strips and on the north side of gaps in compartment 21, and it was found that the butt diameter of shaded trees averaged 74·0 per cent. of that of trees grown in full light, while the corresponding ratio at mid-height was 70·6 per cent. This shows both a marked reduction in diameter and a small change in the taper, or form factor, due to reduction in light intensity. The mean degree of taper expressed as the ratio of diameter at mid-height/diameter at butt was 0·519 in the case of shaded trees and 0·546 for trees in full light. It should be noted that both groups of trees were sheltered from the wind which also affects taper (see section *c*, *Wind*, below).

b. Frost. Minimum thermometers were placed both at ground level and 5 feet above the ground in the open area of compartment 18 and in a typically sheltered gap in the hazel about 20 feet across in compartment 23.

It was found that when temperatures were around or below freezing the ground minimum temperatures in the gap were usually 3–5° F. higher than those in the open, while temperatures at 5 feet above ground in the gap exceeded those in the open by only 0·5–1·0° F. There was no suggestion that the shelter provided by this type of gap in hazel coppice would give complete protection against a sharp unseasonable frost, but one would expect it to reduce appreciably the damage done by temperatures as low as 25° F. during the growing season.

c. Wind. (i) *Effect on stem diameter.* Diameter readings above the butt swelling and at mid-height were taken on 70 trees in compartment 18 which were exposed both to full sunlight and the wind. They were allocated to 1-foot height classes and their measurements were compared with those of the trees on the north side of gaps in compartment 21 (referred to previously in section *a*, (ii) *Effect on stem diameter*, above) which were exposed to the sun but sheltered from the wind; any difference in diameter or taper between these two groups of trees was to be attributed to the effect of the wind.

This showed that there was no significant difference in the butt diameters between the two sites, but that the taper expressed as diameter at mid-height/diameter at butt was 0·546 in the case of trees sheltered from the wind and 0·490 for trees on a slightly exposed site.

(ii) *Effect on height growth.* In the sheltered conditions of the gaps and strips many of the most vigorous beech were making annual height increments of over 24 inches and three trees were found with new shoots of over 50 inches; these leaders first developed as long, soft, pendulous, and fragile shoots which harden and become erect towards the end of the growing season. This is in contrast to the habit of trees exposed to the wind whose leaders were stouter and more or less erect throughout the growing season. Whether the production of a tougher shoot

necessarily makes it shorter is uncertain, but the mean length of leading shoot from 30 of the tallest beech with exposed tops was 12·9 inches, while comparable figures from sheltered trees in the gaps of compartments 21 and 23 were 26·0 inches and 24·9 inches respectively.

It should be noted, however, that while the beech at Gardiner are sensitive to the effects of shelter, similar results are not always found elsewhere and are quite absent on the deeper and moister soils at Collingbourne in Wiltshire.

(iii) *Effect on humidity and the local evaporating capacity of the air.* On moving from the open part of compartment 18 to the sheltered gaps of compartment 23 there was a very marked sensation of increased humidity even on a dry and breezy day in June; however, readings with a wet and dry bulb thermometer failed to show more than 1–2 per cent. difference in the relative humidity at the two sites and this suggested that the damp feeling of the air in the groups was probably due to the reduced air movement.

It was decided therefore to make direct measurements of the amounts of water evaporated from suitable surfaces during the same period but under different conditions of shelter from the wind. The evaporimeters were of the same design, so that under identical conditions the air-flow over the evaporating surfaces and the quantities of water lost by evaporation proved to be almost exactly the same. Nevertheless, in order that the results should not be biased by differences in the apparatus used the evaporimeters were interchanged after each set of readings so that the mean readings for each site were contributed to equally by each evaporimeter.

At first two and later four evaporimeters were used and these showed very marked differences in the local evaporating power of the air due to shelter from wind.

It was found that in warm dry weather at the end of August and first half of September the total amount of water lost in a week by evaporation in the exposed part of compartment 18 was on the average just 10 times the amount lost in a gap in compartment 23, while during a week of continuous rain the ratio was reduced to 3 times; during the cooler weather of October and early November in fine spells the exposed evaporimeter lost about 3–4 times that of the sheltered instrument, while in wet and misty weather at this time the ratio dropped to 1·5–2·5.

It was evident that the factors principally responsible for these different rates of evaporation were:

1. Exposure to wind, or the number of 'miles of air' passing over a given spot.
2. Air temperature.
3. Air humidity.

The master factor seemed to be exposure.

(iv) *The water balance of the plants.* The significance of the figures for water evaporation is that the same factors which control the rate of water loss from an evaporimeter also act on the evaporating surfaces of beech leaves, thus the evaporimeter readings show that the demand made on the water economy of exposed trees greatly exceeds that made on sheltered trees.

In order to maintain photosynthesis beech leaves need to be kept reasonably turgid, and the suggestion is that the crowns of exposed trees need to be supplied, via their roots and vessels, with larger quantities of water in order to remain turgid than do sheltered trees. It seems probable that on sites where the amount of available water is limited trees in exposed positions might be unable to supply their crowns with enough water to keep their leaves turgid so that photosynthesis and growth would be reduced, while trees in sheltered positions would, with the same water intake, keep their leaves turgid and thus maintain photosynthesis and growth.

Evaporation from the leaf surfaces is, of course, only one of the factors involved in the water balance of trees, the other principal factor being the rate of water intake by the roots which itself depends on such matters as rainfall, soil moisture, soil texture, root competition, &c.

The state of 'water deficiency' which results when the potential rate of evaporation from the leaves exceeds the rate at which water is supplied by the roots and vessels is more likely to occur on shallow and dry soils than on moist and deep ones because on the latter type the increased water intake by the roots should be sufficient to keep the leaves turgid even in the crowns of trees suffering a reasonable degree of exposure. In such places one would expect to find little or no benefit from shelter, and this is observed, for instance, at Collingbourne; it is on dry soils, or where there is intense root competition, or where for any reason water uptake is low, that one would expect shelter to result in improved growth.

FACTORS AFFECTING THE FORM OF BEECH

Examination of the P. 46 beech at Stonedown gave the strong impression that their genetic qualities were quite good; they have a definite tendency to make a single leading shoot to which their low-angled side branches are subsidiary, and it was considered that forks and other stem faults would usually have arisen through some environmental factor; this was borne out by the fact that when forks had occurred each of the resulting stems showed the same tendency to make a central axis with smaller side branches.

Therefore an assessment of form was made in each of the areas studied to see whether stem form was connected with some site factor and to try to throw some light on the causes of forking.

Some 1,400 trees growing under a variety of conditions were examined in 1950 and each was put into one of the following categories:

A. Trees with a definite tendency to make one central axis with light side branches.
B. Trees with a definite tendency to make one central axis but with coarse side branches.
C. Much forked and bushy trees with no apparent tendency to make a central axis.

The first two classes were subdivided according to whether their leading shoot and bud were undamaged, or damaged that year, or showed evidence of having

been damaged in previous years, or whether the tree showed one or more distinct forks.

A note was also made of each tree which had made a Lammas shoot in the current year whether it was damaged or not.

It was found that three factors, namely:

1. Light intensity,
2. Damage to leading bud or shoot,
3. Lammas growth, in that it was frequently associated with leading shoot damage,

had significant effects on the form of these young beech.

1. *The effect of light intensity on form*

It was found that when the different sites were classified according to the light intensity received certain differences in tree form were revealed.

TABLE IV. *Effect of light intensity on branch type*

Light intensity	*No. of trees assessed*	*Percentage of trees in each branch type*		
		Light	*Heavy*	*Bushy*
1. Heavy overhead and side shade . .	200	27·5	72·0	0·5
2. No direct light; about half diffuse light	800	21·5	77·8	0·7
3. Most of direct and diffuse light . .	600	13·3	84·3	2·4

Thus there are definitely more trees with light side branches on the sites receiving a smaller proportion of sunlight; this would be expected and ties up with the reduced stem diameter for such sites mentioned in 3*a* (ii) above.

TABLE V. *Effect of light intensity on maintenance of good stem form following damage to leading shoot*

Light intensity	*Percentage of trees which have had leading shoot damage during last 4 years. Some have recovered one central axis while some have forked*	*Percentage of trees which have had leading shoot damage during last 4 years but have recovered*	*Number of trees which have recovered as percentage of those damaged*
1. Heavy overhead and side shade	7·0	2·0	28·6
2. No direct light: about half diffuse light . . .	16·5	9·6	58·2
3. Most of direct and diffuse light	18·0	5·7	31·5

There was a slight difference in the number of trees with leading shoot damage corresponding with the different sites, but this was not very significant; however,

it was found that there was an important difference in the proportion of damaged trees which recovered and maintained a single leading shoot, and the relevant figures are shown in Table V above.

Thus there is evidently a strong suggestion that a damaged beech under conditions of moderate shade is more likely to recover good stem form than either a tree under heavy shade or one in full daylight.

2. *The effect of damage to leading buds*

An examination of the numbers of trees on each site which had actually forked showed a clear correlation with the total number of trees which had suffered damage in previous years, and this is expressed in Fig. 1.

The total number of trees shown as damaged includes those which forked and those which did not.

This suggests that at Stonedown and with this particular race of beech the number of forked trees is not solely a matter of genetic tendencies but depends to an important degree on the extent of physical damage to the leading bud or leading shoot.

3. *The effect of Lammas growth*

During the assessment it became clear that a very high proportion of damage to this year's leaders had occurred on trees which had made Lammas shoots, and that damage was rare to leading buds which had hardened off normally. The agents causing this damage seem to have been mixed; some of the shoots seemed to have been killed by frost, some by an unidentified lepidopterous larva, and some possibly by aphids. Not all the damaged Lammas shoots were killed, but many were seriously deformed and had up to six vigorous buds on the terminal inch, and it seemed probable that in the following year each of those side buds would make an equally vigorous shoot and the tree would no longer have a central axis.

The relation between Lammas shoots and damage to leading shoots or buds is shown in Table VI below.

Table VI. *The relation between the presence of Lammas shoots and leading bud damage*

No. of trees examined	*Percentage of trees with Lammas shoots*	*Percentage of trees with Lammas shoots which had damage to current year's leading shoot*	*Percentage of trees without Lammas shoots which had damage to current year's leading shoot*
1,400	54·8	26·1	5·9

Thus the figures recorded during the assessment supported the visual impression that Lammas shoots had been an important source of damage; as Fig. 1 shows that a greater proportion of damage to leaders results in more forks, it can be said with some certainty that at Stonedown Wood the Lammas shoots of 1950 will frequently lead to forking.

Although the tendency to make Lammas shoots is probably inherited and may vary between different races of beech, it is certainly much influenced by environment, and the collected data showed that Lammas shoots occur more frequently where all the factors affecting growth are favourable but where any one factor

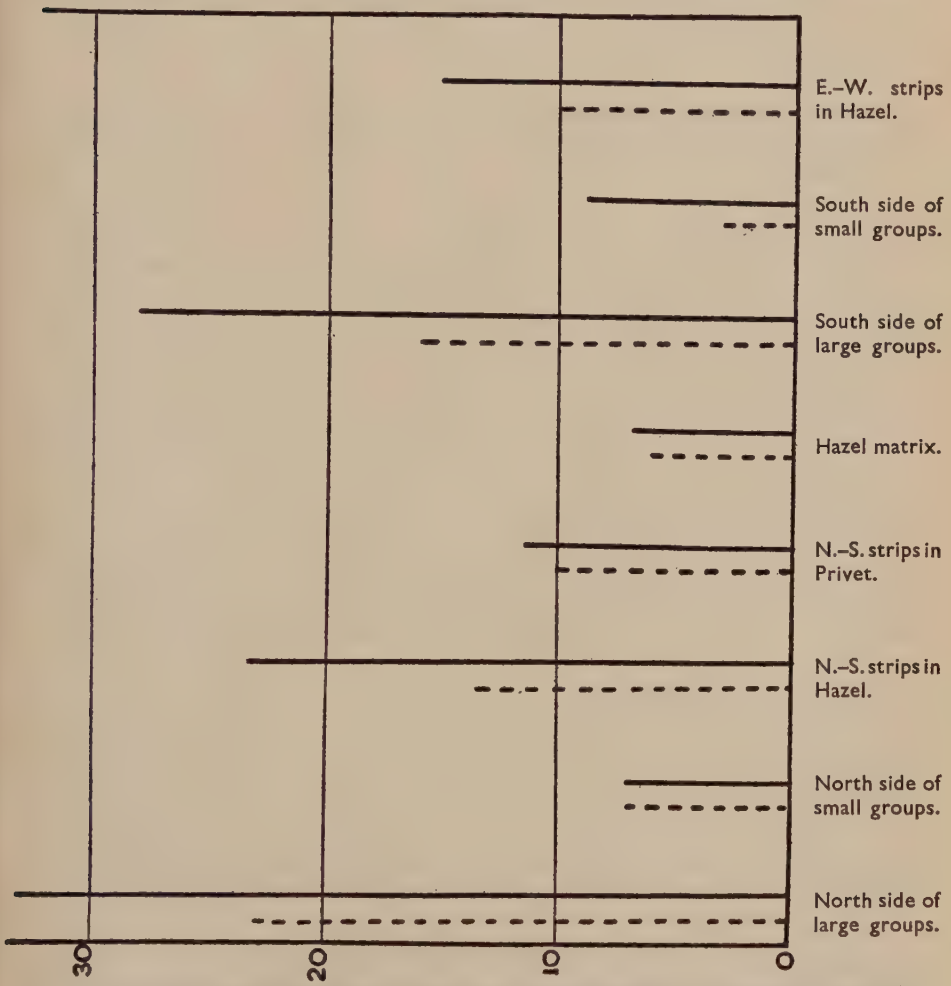

FIG. 1. Correlation between numbers of trees with damaged leaders and numbers of trees with forks. ——— % of trees which have suffered damage to their leading shoots since coming out of check. - - - - - % of trees which have developed forks since coming out of check.

tends to reduce growth, for instance if the trees were exposed to wind or where the light intensity was too low for vigorous growth, the proportion of trees with Lammas shoots fell markedly. Table VI shows that of a large number of trees 54·8 per cent. had made Lammas growth, but where the beech were planted amongst the privet in compartment 18 only 12·0 per cent. had Lammas shoots and of the trees in the heavy shade in compartment 21 only 8·5 per cent. had made Lammas growth.

In normal afforestation with beech this question of Lammas shoots is probably not very important because there is a large number of trees from which to select the final crop, but in systems using small groups or even individual trees where a very high proportion of the planted stock will form part of the final crop the effect of Lammas growth on stem form may become very important.

CONCLUSIONS

It appears that the following conclusions may be drawn as a result of this study, though it must again be emphasized that they may apply only to young beech on chalk sites.

1. Soil depth over the chalk has no effect on beech growth for the first several years after planting.
2. Even after a long dry spell in midsummer these shallow soils contain enough moisture to permit growth, and soils associated with hazel shelter and an herbaceous flora are slightly more moist than those associated with privet, dogwood, and a flora of grasses and sedges.
3. The shelter provided by hazel hedges has little influence on soil temperature.
4. Variations in soil fertility occur very locally and probably affect the height growth of beech.
5. Root competition with privet and dogwood can be a critical factor in determining whether or not transplants become established satisfactorily, but root competition from dense hazel is not injurious to beech.
6. The light intensity falling on young beech crowns, measured as diffuse light, may be reduced to about half of full daylight without causing any loss of vigour in the trees, but if light is cut to as little as one-third of full daylight, there will be a reduction of beech height growth.
7. Hazel hedges separating groups and strips provide rather unreliable shelter from frost.
8. Hazel hedges provide considerable shelter from wind, and one important result of this is the reduced rate of evaporation from moist surfaces; it is thought that such shelter would reduce the rate of transpiration from leaf surfaces and that on sites where water-supply is not abundant this would affect leaf turgidity and rate of photosynthesis.
9. There was no significant difference in the incidence of forks between sites receiving full daylight and those with varying degrees of shade, but a damaged tree was more likely to recover good stem form if it were in a shaded position.
10. The number of forks is closely related to the incidence of leading shoot damage, and Lammas shoots are an important source of leading shoot failure.

ACKNOWLEDGEMENT

This paper is published with the permission of H.M. Forestry Commissioners.

FAST-GROWN WOOD, ITS FEATURES AND VALUE, WITH SPECIAL REFERENCE TO CONIFER PLANTING IN THE UNITED KINGDOM SINCE 1919

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SUMMARY

The rates of growth and timber quality of the seven chief species of conifer grown in the U.K. are examined. These rates in the plantations of the quality classes expected to be most common in the U.K. range on the average from 8 or 9 annual rings per inch for Sitka spruce (*Picea sitchensis*) and Douglas fir (*Pseudotsuga taxifolia*) to 13½ for Scots pine (*Pinus sylvestris*). This is at least 2½ to 1⅓ times as fast as the growth rate (20 rings and up) of much of the soft-wood imported into the U.K. from the Baltic and Canada, other than second-growth or other fast-grown Douglas fir. The evidence on the timber quality of the relatively fast-growing crops in the U.K. is encouraging, assuming that excessive knots are eliminated or reduced by good tending, including pruning where that is justified. The relations between growth rate and timber quality are reviewed in some detail, as it is well known that other factors, including specific gravity, late wood (summer-wood), and ring age or position relative to the pith are important. The relevant evidence from other countries is reviewed and suggestions are made for further research. In this field collaboration between silviculture and forest products research is particularly important.

INTRODUCTION

THE object of this paper is to invite discussion of a field in which collaboration between silviculture and forest products research is particularly important. The subject is of special interest to those countries which have planted large acreages of fast-growing conifers, New Zealand, South Africa, Australia, East Africa, the U.K., &c., or have large current planting programmes. It is also of increasing importance throughout the world, in hardwoods as well as conifers, because the slowly accumulated wealth of virgin timber in the form of very large trees is being used up. As populations and demands increase, in North America and everywhere else the continuing timber supplies of the future will be inevitably from smaller, younger, and faster-grown trees than in the past. Sustained yield is now a normal objective of enlightened growers and consumers, but the implications of smaller, faster-grown trees call for discussion.

2. The emphasis in this paper is on timber quality in relation to the time taken to grow the timber, or, in brief, the number of annual rings per inch of radial growth of the tree bole. Well-known evidence proves that the number of annual rings per inch, alone, is not an adequate or safe index of quality; but with proper regard for other factors, such as specific gravity, ring age and position in the tree, nature of late wood (summer-wood) and its percentage and distribution, the annual rings per inch are a useful pointer, and they do tie up definitely with the

age, size, and cost of the crop. Volume of wood per acre, at various ages, is a more familiar subject of discussion by silviculturists than the timber quality of the wood itself; and the external form and health of the tree is studied more often than what is happening inside. The ideal is to consider all aspects, including the effect on the soil if fast-growing crops are clear felled when relatively young. As a start this paper sets out some of the evidence from the U.K. on timber quality in relation to age and growth rate, refers briefly to the reports from other countries on the same subject, and suggests certain questions for discussion and further study.

THE PRESENT SILVICULTURAL POSITION IN THE U.K. IN OUTLINE

3. Table I below shows the total area of plantations of each of the seven major conifers in Great Britain standing at 30th September 1947, the basic date of the last census of woodlands, and the corresponding figures by the decades in which these plantations were made, from data supplied by the Forestry Commission. The figures have been rounded to the nearest 1,000 acres. They include both private woodlands and State forests. Some very minor differences from Tables 5 and 7 of the Summary Report of the Census (12) are unimportant.

TABLE I. *Coniferous plantations (acres) in private woodlands and State forests combined (U.K.), standing at 30.9.1947*

Species	*Planted before 1.10.1917*	*Planted 1917–27*	*Planted 1927–37*	*Planted 1937–47*	*Total*	*Per. cent.*
(1) Scots pine (*Pinus sylvestris*)	174,000	67,000	72,000	51,000	364,000	39
(2) Sitka spruce (*Picea sitchensis*)	6,000	17,000	66,000	78,000	167,000	18
(3) Norway spruce (*Picea abies*)	29,000	20,000	38,000	46,000	133,000	14·5
(4) European larch (*Larix decidua*)	52,000	26,000	36,000	19,000	133,000	14·5
(5) Japanese larch (*Larix leptolepis*)	4,000	11,000	21,000	19,000	55,000	6
(6) Corsican pine (*Pinus laricio* var. *calabrica*)	4,000	8,000	17,000	10,000	39,000	4
(7) Douglas fir (*Pseudotsuga taxifolia*)	7,000	15,000	12,000	4,000	38,000	4
					929,000	100

Table II shows the corresponding data for the period 1937–47, separately for private woodlands and State forests, to illustrate the current choice of species for planting, which differs appreciably from the choice in earlier decades.

4. Tables III and IV have been prepared wholly or mainly by the Research Branch of the Forestry Commission, Alice Holt, and special acknowledgements are due to Mr. F. C. Hummel and Mr. J. M. Christie of the Mensuration Section

TABLE II. *Coniferous plantations (acres, U.K.) of 1937–47, standing at 30.9.1947*

Species	*State forests*	*Private woodlands*	*Total*	*Per cent. of the species in State forests*	*Per cent. of the species in all forests*
(1) Sitka spruce .	72,000	6,000	78,000	42·5 } 66·5	34·5 } 54·5
(2) Norway spruce .	40,000	6,000	46,000	24 }	20 }
(3) Scots pine . .	27,000	24,000	51,000	16	23
(4) Japanese larch .	13,000	6,000	19,000	8	8·5
				(+3·5* = 11·5)	(+8·5* = 17)
(5) Corsican pine .	9,000	1,000	10,000	5	4
(6) European larch .	6,000	13,000	19,000	3·5*	8·5*
(7) Douglas fir .	2,000	2,000	4,000	1	2
	169,000 (75 per cent.)	58,000 (25 per cent.)	227,000 (100 per cent.)	100	100

for their co-operation in this work. The data are provisional but based on a large number of sample plot measurements, and therefore widely representative. Table III explains itself, and silviculturists will be interested in the data on number of stems and standing volume per acre. However, the main purpose is to direct attention to the annual rings per inch, as a pointer to the probable timber quality, where other factors do not disturb this quality materially. Table IV shows the average number of annual rings per inch in the stems measured. It is clear from the table that the rate of growth slows down as the tree grows larger, and, indeed, as is well known, the core-wood of most species has fewer and wider rings per inch near the pith than can be deduced by simply dividing the age by the radius under bark, even at 6 or 9 inches diameter; for such division gives only an average number of rings per inch, from pith to bark. However, the data are a useful indication of the general pattern and are correct as average figures.

5. A further factor should be mentioned, with a similar influence. The girths of Table III, on which Table IV is based, are the mean girths of the sample plots at the successive ages. These mean girths of the whole plot are below the mean girths of the 100 largest trees in the plot, especially at the younger ages; and the final crop trees are likely to resemble or consist mainly of the 100 largest trees rather than the mean tree of any given plot in youth or middle age. A few data on this effect are available and illustrate the point. Thus in certain Sitka spruce plots of Growth Quality Class III, the figures were found to be as follows:

Diam. (inches) under bark of mean tree	*Average diam. (inches) under bark of 100 largest trees*	*Age in years*	*Average annual rings per inch, mean tree*	*Average annual rings per inch, 100 largest trees*	*Difference*
6	8	26	9	6·5	2·5
9	11·5	28	8·5	7	1·5
12	13·6	51	8·5	7·5	1·0

This factor disappears eventually, when the older and larger trees, approaching maturity, are being measured in the sample plots, at least as far as the average number of rings per inch, from pith to bark, is concerned; but it will affect the pattern of growth of the final crop trees, within their average. Such trees will tend to have fewer rings per inch in their youth and middle age than the Table IV figures, based on mean tree measurements. On the other hand, the intermediate yield trees, removed in thinning, will conform to the Table IV data.

TABLE III. *Growth data for the seven chief coniferous species grown in the U.K., primarily to show age against diameter*

Breast ht. diam. U.B.	*Equiv. B.H. girth U.B.*	*Bark per cent.*	*Equiv. B.H. girth O.B.*	*Top height at which reached*	*Age*	*Av. vol. O.B. per tree*	*No. stems per acre*	*Standing vol. per acre*
(*in.*)	(*in.*)		(*in.*)	(*feet*)	(*yrs.*)	(*boppus feet*)		(*boppus feet O.B.*)
			(1) SITKA SPRUCE (Q.C. III)					
6	19	11	20	49½	26	3·80	620	2,355
9	28½	10	30	73	38	13·2	270	3,565
12	37½	9	39½	92	51	27·8	160	4,450
15	47	8	49	105½	63	43·7	140	6,120
18	56½	7	58½	116	73	..	..	..
			(2) DOUGLAS FIR (Q.C. III)					
6	19	12½	20½	49	24	3·46	520	1,800
9	28½	12½	30½	68	34	11·0	290	3,190
12	37½	12½	40	86	46	23·9	195	4,660
15	47	12½	50½	104	63	43·7	140	6,120
18	56½	12½	60½	120	81	69·8	105	7,330
			(3) CORSICAN PINE (Q.C. II)					
6	19	20	21	45	29	3·96	610	2,415
9	28½	19	31½	67	47	13·7	280	3,835
12	37½	18	41½	85	69	27·7	165	4,570
15	47	18	52	103	..	53·0	120	6,360
18	56½	18	62½	119	..	..	..	..
			(4) JAPANESE LARCH (Q.C. II)					
6	19	17	21	49	30	4·10	315	1,290
9	28½	16	31	68	46	12·9	160	2,065
12	37½	14	40½	85	75	27·0	110	2,970
15	47	14	50½	100½	..	..	..	..
18	56½	14	61	116	..	..	..	..
			(5) EUROPEAN LARCH (Q.C. II)					
6	19	20	21	51½	30	4·27	300	1,280
9	28½	19	31½	70	50	14·0	150	2,100
12	37½	18	41½	85	75	28·1	110	3,090
15	47	18	52	100	..	51·1	90	4,600
18	56½	18	62½	114	..	83·3	80	6,665

TABLE III—*continued*

Breast ht. diam. U.B.	*Equiv. B.H. girth U.B.*	*Bark per cent.*	*Equiv. B.H. girth O.B.*	*Top height at which reached*	*Age*	*Av. vol. O.B. per tree*	*No. stems per acre*	*Standing vol. per acre*
(*in.*)	(*in.*)		(*in.*)	(*feet*)	(*yrs.*)	(*hoppus feet*)		(*hoppus feet O.B.*)
			(6) NORWAY SPRUCE (Q.C. II)					
6	19	11	20	50	33	3·91	640	2,500
9	28½	10	30	73	53	13·2	280	3,695
12	37½	9	39½	91	76	27·5	175	4,810
15	47	9	50	107	..	45·9	150	6,885
18	56½	9	60	120	..	..	..	..
			(7) SCOTS PINE (Q.C. II)					
6	19	16	21	45	35	3·41	550	1,875
9	28½	15	31	66	57	11·2	240	2,690
12	37½	15	40½	83½	88	23·6	145	3,420
15	47	14	50½	101	..	45·4	100	4,540
18	56½	14	61	117	..	78·4	80	6,270

(Volumes based on timber down to a diameter of 3 in. over bark.)

U.B. = under bark.
O.B. = over bark.
Q.C. = growth quality class, I, II, III, judged by height for age.
Hoppus = volume found by length × the square of ¼ of the girth.
This is 78·5 per cent. of the true volume.
1 hoppus foot = 1·273 cubic foot true measure.
1 cubic foot true measure = 0·785 hoppus foot.
This is constant, irrespective of the diameter of the log.

The growth quality class tabled for each species is that in which a major portion of the timber now being grown is likely to fall when ripe.

6. In respect of the growth rate and timber quality the chief features of the above data are as follows:

(1) All the growth rates in terms of the average number of rings per radial inch, from pith to bark, are reasonable and encouraging as to timber quality. They are slower than the maximum rates which considerable but incomplete work to date has suggested as prudent in respect of timber quality in the U.K. (This work is reviewed below.)

(2) The fastest U.K. growth rate of 8 rings per inch is equal to the slowest rate aimed at in South Africa with *Pinus patula*, *P. radiata* (*insignis*), &c., the South African expectation being 4 to 8 rings per inch.

(3) The U.K. growth rates are 2½ times as fast (Sitka spruce and Douglas fir) as the rate of 20 or more rings per inch common in conifers imported into the U.K. from the Baltic and Canada, and 1⅓ times as fast as the imported

TABLE IV. *The average number of annual rings per inch in timber of the seven chief coniferous species grown in the U.K. deduced from age at various diameters in typical growth quality classes*

Species and growth quality class	Diameter under bark, breast height (in.)									
	6 in.		9 in.		12 in.		15 in.		18 in.	
	Age in years	Annual rings per inch†	Age in years	Annual rings per inch†	Age in years	Annual rings per inch†	Age in years	Annual rings per inch†	Age in years	Annual rings per inch†
Sitka spruce Q.C. III	26	9	38	8·5	51	8·5	63	8·5	73	8
Douglas fir Q.C. III	24	8	34	7·5	46	8	63	8·5	81	9
Corsican pine Q.C. II	29	10	47	10·5	69	11·5	..*	..	..	..
Japanese larch Q.C. II	30	10	46	10	75	12·5	..	..	..	..
European larch Q.C. II	30	10	50	11	75	12·5	..	..	..	..
Norway spruce Q.C. II.	33	11	53	12	76	13	..	..	..	..
Scots pine Q.C. II	35	12	57	13	88	15	..	..	..*	..*

† Average rate from pith to bark.

* No data available.

timber growth rate, in the case of home-grown Scots pine (*P. sylvestris*) (The second-growth or other fast-grown Douglas fir from the Pacific Coast is an exception and may show only some 6 rings per inch.)

(4) The seven major conifer species being planted in the U.K. can be classified by timber growth rate as follows:

Fast	Sitka spruce
	Douglas fir
Moderately fast	Corsican pine
Normal for the U.K.	Norway spruce
	European larch
	Japanese larch
Slow	Scots pine

(5) It may be necessary to take account of the following factors in special cases, where they are of appreciable importance in the general picture:

(i) Trees with very fast cores and slower outer wood, although showing a reasonable general average rate of growth.

(ii) The growth quality classes higher than those estimated as a common average for the country, where the higher quality classes grow much faster.

(iii) Undesirable compression wood and imperfect late wood formation, especially in Sitka spruce. (See paragraphs 13 and 31 below.)

WORK TO DATE ON TIMBER QUALITY IN RELATION TO RATE OF GROWTH OF CONIFERS IN THE U.K.

7. During 1941–7 2,000 home-grown pit-props from normally thinned plantations in twenty-five localities of England, Scotland, and Wales, including all seven of the major conifer species listed in paragraph 6 (4) above, were sent by the Forestry Commission to the Forest Products Research Laboratory, Princes Risborough, Bucks., and tested for strength in compression, as whole props. The results have been published in detail, with a statistical analysis, in a paper by F. H. Armstrong (2).

8. It was found that when the number of annual rings per inch fell below 8 for home-grown Scots pine or 6 for the other six species examined (two spruces, two larches, Douglas fir, and another pine), the density and strength in compression of the props began to decrease materially for the use in view. The top diameters under bark of these stems were 2½ to 5½ inches and their ages were from 17 to 38 years, in the case of the three fastest-grown species, Japanese larch, Sitka spruce, and Douglas fir. (Japanese larch slows down later in life but is fast up to pit-prop sizes.) The average number of rings per inch of the 2,000 props was 13½ for Scots pine, 10½ for Norway spruce, 8½ for European larch and Corsican pine, 8 for Douglas fir, 7 for Sitka spruce, and 6½ for Japanese larch. These rates of growth are all slower than the maximum rate for reasonable pit-prop strength in each species. Thus the results were favourable and encouraging, and in line with general experience in the two world wars.

9. Between 1932 and 1941 a general study of the strength and other properties of home-grown Sitka spruce of 48 to 70 years of age was made at Princes Risborough, and an intensive study of strength in compression in relation to rate of growth, specific gravity, ring age, and nature and distribution of the late wood. The results have been published in detail, with a statistical analysis, in an official report by E. W. J. Phillips (33), which sets out clearly the rather complex details. (The report has a very full list of references to the work of other investigators and a summary of Trendelenburg's full discussion of the variation of specific gravity within the tree and between trees (41).) Dr. Phillips's main findings on the timber properties associated with the rates of growth examined, the nature and distribution of the late wood in the annual ring, and the position of any given sample or piece of timber relative to the pith of the tree, or vertically in its bole, were as follows.

On annual rings per inch

10. Of the 14 trees examined all 9 from one locality (two sites in Argyllshire) averaged 8 rings per inch, in contrast to the 5 other trees, from 4 other localities, which averaged only 4 rings per inch. The strength in compression was fairly uniform within each of these two sets and was 24 per cent. higher in the slower grown (8 rings per inch) than in the faster grown (4 rings per inch).

11. The tests suggested that usually a rate of 6 rings per inch (4 mm. ring width) was not too fast for satisfactory strength. The same figure is suggested in Mr. Armstrong's report on pit-prop tests (paragraph 8 above). The average growth rate of Sitka spruce in the U.K. as a whole is expected to be slower than 6 rings per inch (paragraph 4 and Table IV above).

On the importance of the nature, distribution, and amount of the late wood in the annual rings

12. Dr. Phillips distinguishes and illustrates by photographs three grades of late wood—dense, medium, and light—and two main types of annual ring, depending on the distribution and grade of their late wood. These differences in the nature of the annual ring complicate the relations between ring width, density, and strength. Thus ring width is a more accurate pointer to timber quality if the grade, distribution, and amount of the late wood in the ring are taken into account also. Moreover, if radial position in the tree, and late wood, can both be taken into account, together with ring width, a much closer estimate of the strength is possible, without knowing the specific gravity of the wood. How far that is practicable in commercial grading is another matter, but an interesting example of the possibilities is quoted in paragraph 35 below.

13. Dr. Phillips also comments on the fact that Sitka spruce grown in the U.K. varies in late wood development independently of its growth rate (foot of page 27 of his report), and mentions site effects and the effect of chemical composition of the cell wall. More recently Mr. W. R. Day of the Imperial Forestry Institute, Oxford, has been finding evidence that home-grown spruce, both Norway and Sitka, varies materially in its behaviour, according to its race or strain, and that

this variation may extend to the nature and amount of the late wood formed in a given year and locality. Where late wood is inadequate the timber quality may be unsatisfactory or the tree liable to disease (9). The importance of this factor is obvious. It merits study as much as the rate of growth, because quality may be affected vitally, independently of the rings per inch of the timber. Similarly in other species the variation of late wood and specific gravity with factors such as the available moisture has been described by Benson H. Paul and Ralph O. Marts for *Pinus palustris* in the U.S.A. (25) and by G. Penn Barrow and L. Chalk for Douglas fir in the U.K. (3, 5).

Core-wood effects shown by the first 10–15 annual rings around the pith

14. The strength in compression of the wood increases from the pith outwards. Although the specific gravity decreases radially for the first 10 to 15 annual rings and then increases progressively towards the bark, the usual relation between strength and specific gravity is disturbed by fibril angle, at the core. Wood near the pith is low in strength for its specific gravity. (Wood from near the butt is also weaker than wood from near the middle of the bole length.)

15. The fibrils of the tracheid walls vary in the angle which they make with the vertical axis of the tracheid. This angle is greater at the pith and decreases rapidly outwards, in successive rings, especially in the first 10 rings. The evidence suggests that the low strength near the pith, in the first 10 years or so, is due to the greater fibril angle, independently of the specific gravity and ring width (34). This agrees with the work of Koehler of Madison, who has pointed out that a large fibril angle is associated with low strength and high longitudinal shrinkage, and is found in wide-ringed wood near the pith of fast-growing pines such as *Pinus palustris* of the south-east of the U.S.A. (20). (Obviously there may be merit for certain purposes in a slower grown and narrower core of the weak wood formed in the first 10 years, compared with a faster grown and wider core of such wood.)

16. Between 1926 and 1939 the Forest Products Research Laboratory, Princes Risborough, tested all or most of the major home-grown timbers of the U.K. The data are available in *A Handbook of Home-grown Timbers*, 1941, and subsequent reprints (16). Bulletins Nos. 6, 10, and 15 (13, 14, 15) also give fuller accounts of the testing of Corsican pine, Douglas fir, and Scots pine. From these and other reports the following evidence on rate of growth effects or associations is culled for the chief conifers.

17. In the Corsican pine tested, the average number of rings per inch was 6 to 8, and the optimum for strength appeared to be 8 to 10. (The average rate of growth of the common current plantations of this species in the U.K. is 11·5 rings per inch.)

18. In the Douglas fir tested the average number of rings per inch was from 4 to 6. The tests suggested that very fair strength was associated with 6 to 7 rings per inch or preferably 10 rings. The average rate of growth of this species in the U.K. is about 8 or 9 rings per inch. Moreover, it may be noted in passing that home-grown Douglas fir railway sleepers, incised and pressure creosoted, have behaved very well indeed in tests in the main-line tracks of British Railways for

the last 16 years (since 1935). Their rate of growth was not recorded, but was presumably normal for the home-grown timber.

19. In the Scots pine tested the range of growth rate in four lots was from 4 to 23 rings per inch, with a general average of about 12 rings. The trees were from 80 to 160 years old and had grown at from 200 to 1,000 feet above sea-level. The tests suggested that for good strength a rate of 9 rings per inch was the fastest permissible, and a rate of 12 rings was preferable, indeed gave approximately maximum strength. Also at 12 rings per inch the appearance of the home-grown wood was better than at 9 rings and compared favourably with that of the good-quality joinery grades of Scots pine normally imported.

20. The imported Scots pine tested for comparison came from the Baltic and the White Sea. Its growth rate ranged from 7 to 66 annual rings per inch, and showed maximum strength at 25 to 35 rings. It was concluded from the tests that in parts of the U.K. very good Scots pine timber can be grown at twice the rate it grows in the Baltic or White Sea regions, and such home-grown wood compares favourably in strength with the imported. The average rate of growth of Scots pine in current U.K. plantations is about 15 rings per inch.

21. Apart from strength properties, the question of the natural durability of fast-growing Japanese larch is often raised, relative to European larch. Allowing for cases of poorer performance as fence posts or fishing-stakes, often reported by consumers, which may be due to very fast grown core-wood, it is to be noted that graveyard tests of Japanese larch with 6 rings per inch, in progress at Princes Risborough and Thetford since 1935 and still going on, show about the same durability as that of European larch with the same number of rings per inch, in the same tests (39). Also, attention is invited to Table IV, which shows that when mature the Japanese larch is no faster on the average than the European; and to paragraph 8, where encouraging evidence on Japanese larch as a pit-prop is recorded, though at that small diameter (2½ to 5½ inches) it had only 6½ rings per inch, against 8½ rings in European larch of the same size. (The average strength of the Japanese species, in the tests made on over 300 props, was 7 per cent. below that of the European larch but was equal to that of Scots pine props with 13½ rings per inch, and was quite satisfactory.) Thus both in natural durability and in strength the timber of Japanese larch comes out well, if stems with excessively fast growth or an undue proportion of core-wood are excluded; and this is satisfactory because the species is hardy, quick to suppress weeds, and more tolerant as to soil, and less subject to canker than European larch.

22. In 1951 a fresh start was made on testing Japanese larch in the form of logs, 46 years old, supplied from a good, privately owned plantation in which the Forestry Commission has maintained a sample plot since 1922. Thus very full silvicultural details are available. Rings per inch, specific gravity, and strength in small clear specimens and in structural sizes are being measured, taking account of ring age and distance from the pith. First indications are favourable, but the data are not yet available.

23. In 1951 also a survey of wood density or specific gravity was started in co-operation with the Research Branch of the Forestry Commission. Under the

trial scheme now in operation, the regular sample plot measuring staff of the Commission, when they fell thinnings in suitable Sitka spruce plots, cut one or more short billets from the boles at agreed heights. They send these to Princes Risborough with very full silvicultural data on the plot and trees concerned. Disks from the billets are then rapidly assessed for average radius and rings per inch, and specific gravity (oven dry weight–green volume). Some 600 billets from 300 trees were expected to arrive at Princes Risborough in 1951–2. The object is to survey as quickly and simply as possible a wide sample of the wood of this species, which is now being planted more than any other in the U.K., and is one of the two fastest growers. The survey will provide a useful pointer to the probable timber quality of the crops and can be used to guide current planting policy, taken in conjunction with other factors.

CONCLUSIONS FROM CURRENT SILVICULTURE AND TIMBER QUALITY IN THE U.K., AND SUGGESTIONS FOR RESEARCH IN THIS FIELD

General

24. The general picture is encouraging. The oceanic climate and the forest soils of the U.K. enable that country to grow good timber, especially softwood or conifers, relatively fast. (The details have been given in paragraphs 4 to 6 above.) Laboratory tests and the large-scale experience of two wars have proved the potentialities of home-grown timber. Knots and lack of seasoning and grading are avoidable by proper silviculture and utilization. These defects should be distinguished from properties which are more or less inherent, such as rate of growth, specific gravity, strength of clear wood, durability, stability, and ease of working, some or all of which are less easily controllable except by choice of species or race, or any variation of spacing or thinning that may be practicable.

Choice of species

25. The advantages of fast growth are obvious, if the timber is of reasonable quality and the trees are healthy. The fast-growing Sitka spruce which is being planted extensively in the U.K. promises to be satisfactory in timber quality, if races of the species which do not develop satisfactory late wood in the U.K. (paragraph 13) or sites where such wood is not developed are avoided.

26. Similarly the Japanese larch which grows fast in youth promises very satisfactory mature timber if too much is not expected of it in small sizes, as stakes and posts, particularly when specially fast grown. Weakness in core-wood formed in the first 10 to 15 years is not incompatible with good quality in the later formed wood of the same species on the same site.

Spacing and thinning

27. On the evidence so far available, no change in the current practice of the Forestry Commission as to spacing and thinning appears to be called for on the grounds of timber quality, at least in the plantations of average growth quality class. It may be worth examining the higher quality class plantations of the fastest species, Sitka spruce, Douglas fir, and Corsican pine, to see if there is a case, at

least in some areas, for restraining the rate of growth in the interests of timber quality, if that is possible by closer spacing or lighter thinning, without undue increase of the cost of establishment or undue sacrifice of volume production. On the whole the evidence so far suggests that, with pruning to reduce knots, a larger volume of very fast grown and perhaps less strong wood will be preferable to a smaller volume of slower grown and stronger wood, provided the very fast wood is serviceable for most large-scale uses such as building and box-making.

Pruning

28. The reduction of knots by pruning is covered only incidentally in this paper. The prevalence of knots and their effect on timber quality are such that it would be wrong to omit reference to them. Obviously, fast growth affects the rate at which a tree heals over its pruned snags, and the lengths of internodal wood, free of knots in species with branches mainly in whorls; but consumers of fast-grown wood are apt to judge it largely by the knots present rather than the merits of the clear wood. This is unfair, and the effects of these two features, knots and fast growth, should not be confused, for they are distinct though connected.

29. Much brashing of side branches to about 6 feet from ground level has been done in conifer plantations in the U.K. but not much high pruning, to date, on a large scale. However, some research on pruning, especially of spruce, has been done by Princes Risborough in co-operation with the Forestry Commission between 1934 and 1951. The main conclusions emerging are as follows (not yet published in detail):

(i) Dissection of some 2,900 pruned knots in home-grown Sitka and Norway spruce from 76 trees and 27 localities of the U.K., in all, and measurements taken on over 1,200 of these knots, show an average radial healing thickness of just under 0·5 inch of wood. From this and growth data from the Forest Research Station, Alice Holt, it appears that if a Sitka spruce tree is pruned to 26 feet in height in three successive operations, to 6, 16, and 26 feet, as soon as the side branches are dead to the height concerned, the healed knotty core should be of a maximum diameter of some 5·5 inches, at which size it would form less than one-quarter of the total volume of the same log if felled at a diameter of 13 inches, when about 50–60 years old; and over three-quarters of the volume of the log should be free of knots. A similar or even more favourable result may be expected from pruned Douglas fir, where pruning of green branches is safer than in spruce.

(ii) The examination of the above 2,900 pruned knots revealed no obviously diseased knots or wood; but from three of the localities the bark of the logs showed suspicious black weeping, similar to that which has been found to be associated with fungal attacks by *Stereospermum sanguinolentum* in the wood of green pruned spruces of both species at Lake Vyrnwy and elsewhere in the U.K. It is felt, therefore, that in line with experience in Germany and Sweden the green pruning of spruce in the U.K. is dangerous in some localities and should be avoided everywhere, normally. Dead pruning appears to avert much of the risk and is satisfactory; *vide* (i) above.

(iii) Such work as has been done on Douglas fir grown in the U.K. suggests that

it may be green pruned with safety. This is in line with the very extensive experience of green pruning various species of pine, outside the U.K., without trouble from disease.

(iv) If clear timber, free of knots, is to be produced quickly on a short rotation, in the U.K., pruning is essential in the major coniferous species, even allowing for what may prove possible by selection of fine branched races or strains. Where growth is fast and the wood is likely to be wanted in grades with few or no knots, pruning appears likely to pay.

Relevant evidence from other countries which have experience of fast-grown wood

30. South Africa has done specially valuable work, associated with the names of I. J. Craib, R. P. Stephens, and the late J. M. Turnbull and M. H. Scott. Their publications describe very serviceable pine timber (*Pinus patula*, *radiata*, *caribaea*, *pinaster*, &c.) being produced in great quantity at 4 to 8 rings per inch, and stress that pruning is an essential feature of their wide planting, heavy thinning, and short rotations. What they have done for their fast-grown softwood by proper seasoning and grading has an obvious bearing on the utilization of the new tree crops in the U.K. and elsewhere (7, 8, 35, 36, 42–46).

31. In the *Empire Forestry Review* of September 1951 (37), in one of M. H. Scott's last articles on exotic pine timber grown in South Africa, he mentions that all the badly warped boards examined had either spiral grain or compression wood. Now work at Madison, U.S.A., by Koehler, Benson H. Paul, and others on southern or longleaf pine has shown the danger of excessive longitudinal shrinkage when the same board includes both very fast core-wood and narrow ringed wood from beyond the fast core; and they also attribute much warping or 'crook' to compression wood; and find that over 70 per cent. of a pine stand may have a lean of 2° or more from the vertical, sufficient to produce appreciable compression wood (29). It seems then that at least three factors, spiral grain, compression wood, and core-wood may cause trouble, in one or another country or species; and as there is some evidence that compression wood is more prevalent in Sitka spruce grown in the U.K. than in home-grown common or Norway spruce, this possible cause of bad warping should be kept in mind.

32. New Zealand's plantations of *Pinus radiata* are on a very large scale. Their tests show satisfactory specific gravity and strength in this pine, even at $2\frac{3}{4}$ annual rings per inch, compared with the allied species, *Pinus ponderosa*, grown and tested in the U.S.A., at 19 rings to the inch (40). Knots and spiral grain appear to cause more concern than the few rings per inch or very fast growth of this New Zealand timber; but in spite of defects it finds very extensive uses and an export market in Australia. No doubt a general shortage of timber causes a general lowering of consumers' standards; but for many uses the consumers' objections seem to be related more truly to factors such as knots rather than a rate of growth faster than previously experienced. (Attention is invited to a recent intensive study of *Pinus radiata* in New Zealand from the pulp and paper angle, with much information on the density and moisture content of the wood (18).)

33. South Australia's Bulletins 3 and 4 of 1950 (4, 19) give a good general

picture of their *Pinus radiata* plantations. The growth data for the trees appear to imply a pattern in the wood changing from 2½ to 3 rings per inch at 11 years of age to 4½ to 5 rings per inch at 26 to 40 years of age. The range of uses is remarkable, in spite of the fast growth, and includes ammunition boxes, flooring, house framing and roofing timber, weather boards, joinery, fruit and dairy cases, plywood, match splints, paper, cardboard, and wall-board. 'In fact, without radiata pine flooring, there would have been no housing programme except at a greatly increased cost for imported timber, if this could have been obtained' (Bulletin No. 3, 1950, p. 19). The strength of this South Australia timber was tested by the Division of Forest Products, Melbourne, and fully reported on in 1938 (6, 22).

34. Slow or moderate rates of growth are more characteristic of Canada, with its northern climate, than very fast growth, and valuable studies of Canadian spruce and Douglas fir variation in specific gravity with rate of growth and age are available (1, 17). In the U.S.A. fast growth in softwoods and hardwoods has been studied at Madison by Koehler, Benson H. Paul, and others, with special attention to longleaf pine (longleaf pitch pine is the trade name in the U.K.), *Pinus palustris*, &c. The literature is considerable (20, 21, 23–32). One of the main findings for the longleaf pine appears to be that rates of growth as fast as 4 rings per inch are consistent with useful strength and stability, particularly if this fast rate is maintained so that the ring width is reasonably even from pith to bark. More recently attention has been given to Douglas fir, on the Pacific Coast, where second-growth trees are becoming increasingly important. Again the general picture is encouraging, provided knots can be dealt with by pruning. Where Douglas fir is wanted for exacting use as prime face-veneers in plywood, some evidence has been found that at growth rates faster than about 10 to 12 rings per inch there is a marked fall in quality, independently of knots (11).

35. In *Tropical Woods*, No. 55, September 1938 (10), there is a description of the successful grading of *Pinus caribaea*, slash or pitch pine, in Nicaragua by visual inspection of the sawn timber, mainly as to the amount and distribution of the late wood in the annual rings, rather than the growth rate. Three grades were separated, having (1) 30 per cent. or more of late wood, mostly in wide dark bands, (2) 20 to 30 per cent. of late wood, mostly in narrow bands, and (3) less than 20 per cent. of late wood, mostly in poorly defined bands. Mechanical testing at Yale showed that these grades, separated by eye, had indeed very different strength values, of practical importance in structural uses, though of less or no importance in some other fields. The rates of growth were not very different, usually 5 or more, 4 or more, and 5 or less rings per inch in the respective grades. This is of interest in view of previous findings in the case of home-grown Sitka spruce regarding the relation between the nature of the late wood and strength variation; *vide* paragraph 12.

36. Finally, to turn for a moment to hardwoods, as opposed to conifers. There has appeared recently (38) a very encouraging detailed report on the timber quality of true teak (*Tectona grandis*) grown in Trinidad from Burma seed. Samples tested at Princes Risborough show slightly higher density and strength for the Trinidad teak at 4 to 6½ rings per inch, compared with Burma teak at 11

rings per inch; and indeed the Trinidad samples showed satisfactory strength even at 2 rings per inch (strength equal to the mean value for the consignment) but a pronounced inferiority at 1 ring per inch. The practical aspect is that by 1990 Trinidad (now planting at 430 acres a year) should be felling some 1½ million cu. ft. a year, on a sustained yield basis, of teak equal in quality to Burma-grown teak. The Trinidad rotation may be some 60 to 80 years, compared with double that time in natural teak forest in Burma, provided the soil fertility in Trinidad can be maintained. The possibilities in other countries with suitable soil and climate for teak are obvious, and the merits of fast growth in hardwoods, at least of this type, are supported.

Suggestions for research

37. The following lines of research are suggested, for conifers:

(1) Simple surveys of wood density, to give the average specific gravity of a disk cut from the bole at one or more suitable heights, of trees of known age felled in normal yearly sample plot thinning by silviculturists. If kept simple this survey should provide data from a large number of trees, with full silvicultural background, including annual rings per inch. (The scheme now working in the U.K. has been described in paragraph 23.) It would be an advantage if general agreement could be reached throughout the world on a standard technique for measuring specific gravity, such as oven dry weight–green volume, or whatever other methods are accurate and practical. That method and also the oven dry weight–oven dry volume method are both in current use at Madison.

(2) Service trials (for each country or region, and each major species) to determine the permissible range of rings per inch and specific gravity for the major uses of fast-grown conifers, such as various items of house-building, box-making, &c. Knot effects should be distinguished from rate of growth, specific gravity, and other effects.

(3) Pruning technique, including tools, bole height to prune, the timing of the operation (by stages, where necessary) according to the size or age and the thinning of the crop, and, in spruces, the death of the branches; diameter of knotty core when healed, total demand for clear wood free of knots, and the cost of pruning relative to the higher price to be expected for clear wood. The species and types of crop which should be pruned, if all species and crops need not or cannot be pruned.

(4) Stability, before and after seasoning, and the woodworking of sawn timber at various specific gravities and annual rings per inch, with special attention to compression wood, spiral grain, and core-wood effects.

(5) Imperfect late wood, its occurrence, causes, and effects on the quality of the timber and the health of the growing tree.

(6) Examination of the timber of important species of typical quality as to annual rings per inch, specific gravity, strength and shrinkage, from pith to bark, and butt to marketable top, taking full account of ring age and distance from the pith. As many conifers appear to have a core of 10 to 15 annual rings of immature wood, or core-wood, the study should aim at separating the effect of core-wood,

if present, from other factors operating outside the core (and possibly within it also), such as rate of growth and specific gravity. (There is evidence that fibril angle may be a major factor in the properties of core-wood.)

ACKNOWLEDGEMENT

This paper, which was presented at the Sixth British Commonwealth Forestry Conference, Canada, August 1952, is published with the permission of the Department of Scientific and Industrial Research.

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REVIEWS

Thirty-second Annual Report of the Forestry Commissioners for the Year ending 30th September 1951. London: Her Majesty's Stationery Office, 1952. 3*s.* net.

Review by C. P. Ackers

THIS report brings home to all interested in our woods and forests one personal sad note. It is the last report to be signed by Lord Robinson. The driving force from start to finish in the building up of an absolutely new government service came from this one man, blessed with a brilliant brain, and with a strong and determined character.

Steady progress in this great work, that is so vital to our country both in peace and war, is shown by the following figures. During the 12 months under review, 113,207 acres have been acquired, bringing the total up to 1,661,390: of this area 56,113 acquired in 1951 are thought to be plantable, bringing the total plantable land to 1,027,821. Of this total 57,164 were planted in the 1951 period, bringing the total planted to date to the high figure of 696,901 acres. Great progress has also been made in enlarging the training facilities for students, in research and experiment, and in the fine work of creating six National Parks (one in Wales, two in England, three in Scotland): some progress has also been made in the Dedication Scheme. All this, together with the high rise in labour costs during the last 5 years, fully explains how the total capital expenditure that was estimated for the past 5 years at a little over £17¼ million has come to just over £26 million. There has been a steady rate of progress in state forestry but planting on privately owned land has been less in the last 1951 period than in 1949 and 1950. This is the more to be regretted because the government grants for planting and maintenance have been increased. One reason may be the mass of work and detail that should go into the survey and plotting of private woodland areas before a dedication scheme can be agreed and completed: less than 75,000 acres had been dedicated up to September 1951.

Any new venture, private or government controlled, must normally proceed by trial and error. As we learn by our failures it is only right that space should be given to constructive criticism. The year 1951 is outstanding in our forestry history for the passing of a very wise Act aimed at conserving our terribly depleted stocks of growing timber. But for most exceptional circumstances, the Act ensures that for the future vast areas are not slaughtered indiscriminately and allowed for many years to remain derelict; in fact one class of timber speculator is put out of business: it ensures that due care is given to thriving young plantations, that they shall be kept to reasonable maturity, in fact that they shall be decently farmed: it also ensures that mature timber must not be allowed to stand too long and become of half-value or less, in fact no longer is a stag-headed oak to be the 'hall-mark of a gentleman's estate'. Under this Act estates that consent to work to a definite agreed sound forestry programme get preference over others in freedom of cutting timber. Why was not this Act passed sooner? Why is not a yearly tax put on to those who continue to hold devastated acres with no attempt to grow timber on them? Bad farmers are rightly dispossessed, bad forestry farmers should be heavily taxed for their gross misuse of land.

Turning to other figures in this report we see that the hoped-for 5-year planting programme for government areas was 290,000 acres and 75,000 for private land. The actual figures are less, namely 218,000 and 63,000, well below the programme. In 1951, 181 miles of all-weather roads were constructed together with 110 miles of fair-weather roads: this

brought the total of new roads constructed for approximately 700,000 acres of woodland to 1,105 miles. Taking account of the few roads that already existed it looks as if government woods were served by only one mile to 500 acres: if this is so, the extraction costs of thinnings must be amazingly high and the sooner the length of roads are quadrupled the better for the country. This and other points brought forward here were very rightly stressed by Professor Champion in his review two years ago. Fires destroyed less than 350 acres in the 12 months, but £142,564 seems a very high year's expenditure: this must be recorded as a good year, as fire losses generally have been heavier. When we come to the figures of trees planted we see that 95 million were used for new plantings and 19 million for replanting failures. As the rabbit menace must be almost negligible over the vast Commission areas we cannot but conclude that planting failures are far higher than for plantings made under normal private enterprise.

Pines, spruces, larches, and broad-leaved trees accounted for 93 per cent. of the species used in planting, leaving only 7 per cent. for that great producer of high-quality coniferous timber, the Douglas fir, together with what the report describes as 'These minor, but very desirable species *Tsuga heterophylla*, *Abies grandis* and *Thuja plicata*'. Have the Forestry Commission their own seed collectors stationed on the Pacific Coast? Supplies of these trees are even more important for renovating the great areas of war-devastated private woodlands, for they, not the Commission's areas, bore the brunt; much of this land is eminently suitable for these very fast-growing, shade-bearing species, which often bear fertile seed in this country. An organized drive should be made to see that as much of this seed as possible is collected throughout the length and breadth of Great Britain.

Co-operation with the general public and their goodwill is mentioned towards the end of the report. This is of vital importance if bitter fights are to be avoided. Lectures, press notices, talks, and special broadcasts are all to the good, but farming and forestry should go hand in hand; something deeper is wanted to create and cement a true and lasting partnership between these two vital sections of land utilization.

Report on Forest Research for the Year ending March 1951. Forestry Commission. London: Her Majesty's Stationery Office, 1952. 4*s*. 6*d*. net.

Review by E. W. Jones

To summarize adequately a report of 139 pages which is itself a summary of work covering a wide range of subjects is impossible within a small space; one can merely indicate the contents and comment briefly on one or two points which personal bias seems to suggest as most important. Most of the statements and findings presented here must, of course, be accepted on trust, for it is impossible to present the evidence in so small a space. It is regrettable that some contributors to the report give mean figures (e.g. for heights of plants) without any standard deviations, which presumably must have been calculated and which are so necessary for appreciating the meaning of the figures.

Research on moorland afforestation and the growth of conifers still accounts for the bulk of the Forestry Commission's research; about fourteen contributions deal with this group of problems, as contrasted with six dealing with or directly connected with growing hardwoods and about a dozen of a more general nature. Throughout the accounts of nursery investigations, provenance trials, work on tree nutrition, and forest entomology only conifers are mentioned and, of the species, Sitka spruce by far the most frequently.

In nursery work perhaps the most important contribution is that concerning weeding. At last there is a good prospect of reducing the cost of weeding very greatly by spraying

suitable oils which seem to be safe and effective when applied to conifer seed-beds just before the emergence of the seedlings and which can be used to some extent after the emergence of pines and perhaps spruces. The work on nutrition and on partial sterilization of the soil continues to be of considerable theoretical interest in its implications, but it leaves us with a feeling that the problems are so complex that progress in understanding them will inevitably be slow, though doubtless steady, for a considerable time.

In the section on provenance studies Mr. M. V. Edwards summarizes the results of the Drummond Hill trial of European larch at an age of 19½ years. The Silesian strain comes first in height, girth, slenderness of branches, and freedom from canker. Some of the Scottish strains come next, but these vary considerably amongst themselves, and some are not appreciably better than the better alpine strains. Further studies on hybrid larch are also reported, and the propagation of the hybrid *Cupressocyparis leylandii* (*Cupressus macrocarpa* × *Chamaecyparis nootkatensis*) is being studied by the geneticist.

Several contributions concern the afforestation of moorlands. Mr. Zehetmayr summarizes the results of several experiments on the best position in which to insert plants into a ploughed furrow; in many sites this is clearly just above the bottom of the furrow; positions on the top are considerably less favourable. Dr. L. Leyton reports that the removal of heather from around young Sitka spruce plants is followed by an increase in the potassium content of the needles and, at a later stage, of their nitrogen content. It is becoming increasingly clear that on sterile heaths and moors the vegetation is starved for nitrogen for which the heather is a serious competitor with the young trees, and the concentration of nitrogen in the foliage of the heather is an indication both of the ability of the soil to supply nitrogen and of its suitability for trees. Mr. P. J. Rennie's work shows that the porosity of the moorland soil is important in determining its fertility, and that in 20 years even the shallow-rooting Sitka spruce can increase the porosity down to 60 cm. depth; this is most heartening, for it means that the prospect of improving the physical properties of a moorland soil and maintaining this improvement by keeping a permanent forest crop on it is good.

There is an interesting summary by Mr. J. A. B. Macdonald of attempts to regenerate naturally some of the indigenous forests of Scots pine in the Highlands. This account emphasizes the difficulties, and stresses the fact that dense vegetation is a frequent cause of failure to regenerate, and that disturbance of the soil may be essential. It is difficult to feel altogether convinced by Mr. Macdonald's argument that the contrast between the difficulty of regeneration today and the apparent ease with which these forests must have regenerated unaided after heavy exploitation in past centuries is to be attributed to the increasing game-preservation and grazing which have changed the balance of fauna in the Highlands as a whole. This seems to be going a long way to find an explanation for something which may need no explanation because it may be an imaginary phenomenon; it must be remembered that we know very little about how rapidly or uniformly or by how direct a course these old forests did regenerate in the past. It also ignores the existence of well-known areas such as the Seafield estates where pine has been regenerated naturally even in recent years. The ecological study of the indigenous pine forests of Scotland, the inception of which has recently been announced, is certainly much needed.

In sections which concern the growing of hardwoods there is a useful summary by Messrs. R. F. Wood and M. Nimmo of experiments with the popular oak-larch mixture. The disparity in growth rate between the 'oak' (the species is not stated, though it might be important!) and larch is greatest on light soils; there is good evidence that the presence of the larch *does* increase the height of the oak. The emphasis throughout these articles on the growing of hardwoods, however, is mainly on beech, and it is evident that this much

neglected but useful species is at last coming into its own. There are two relatively long contributions by Mr. J. M. B. Brown on the effect of shade on young beech and on the performance of beech on various soils, and the beech also figures largely in an important article on the treatment of derelict woodlands and coppice by Mr. A. D. Miller. The experiences with the Weston Common Demonstration Area in Alton Forest, Hampshire, appear to have been more encouraging than some of the Commission's previous experiences with old coppice and devastated woodland, in that it was possible to cover all the initial expenditure by sales of produce. In converting coppice to high forest in Gardiner Forest, Wiltshire, it was possible to sell so much produce that the cost of planting in cleared groups or strips could be reduced to £9–£10 per acre. It would be useful to know how typical these two areas are of any considerable proportion of the country's hardwood forests which need conversion to high forest; it is difficult to avoid a suspicion that Weston Common may be better than the average devastated wood. We are told that it had once carried 'a mature hardwood crop' and that it now had 'dense ash and sycamore regeneration dating from the 1920's', but this is clearly a very imperfect description, as the casual mention of yew and beech regeneration indicates. Obviously the space which is available in a general report of this kind does not permit the inclusion of all the important details, much less all the relevant details. This may serve to illustrate one of the major reflections induced by the report; it is a pity that so much work, much of it of current interest and importance to scientific foresters and biologists both in Great Britain and on the Continent, and to owners of forests, should be carried out and the details never fully published. It may be argued that much of the research by the Commission is designed merely to answer the immediate problems of the Commission, and is of no interest to outsiders, but this work on derelict woodlands and coppice is an example of work which is even more important to the owner of private woodlands than it is to the Commission, and if the Commission is to give him the full benefit of its experience (for which he has helped to pay) full publication of work of this kind, when it has reached a suitable stage, is essential.

There has indeed been a great increase in the amount of information published in recent years, and the appointment of a publications officer shows that the Commission is aware of the importance of this activity, but perhaps I may be permitted to take this opportunity of emphasizing the importance of publication not merely of brief summaries of conclusions, but of full accounts with evidence, of the more important pieces of work.

The lack of published accounts of Commission research is something of which a reviewer such as myself who is endeavouring to train foresters is acutely conscious. When a student asks where he can find information about certain developments, it is not very helpful to have to say 'There is a long paper in the *Zeitschrift für Forst und Jagdwesen*, and if you read Swedish you will also find some important accounts in the *Meddelanden*; the Commission have also carried out many experiments on this matter, but the results have never been published and are unknown, even to myself.' The critical faculties of a student are not developed by brief statements of conclusions, nor by 'recipes' such as those published in the Forest Operations series, however useful these may be to those with no professional training; he needs to be let into the secrets of research and shown the basis for conclusions and recommendations. Nor is it very helpful to have to reply to a query from a foreign colleague about the results of English research—as I am having to do to a query which lies on my desk at this moment—'the Commission have done the work but the results are not published'. Apart from this, publication enhances the reputation and status of the research staff, the care needed in preparing work for publication itself provides valuable training, and the knowledge that the work is to be subject to the criticism not merely of a few

administrators, who would probably be content with reading a summary, but to that of the scientific world in general is a great stimulus to thorough and careful work.

Amongst other items in this report, the inclusion for the first time of a brief note on 'Machinery Research' deserves special mention. There are also notes recording steady progress in mensuration and statistical work, on the afforestation of opencast ironstone workings, on the poisoning of rhododendron, heather, and hazel, on the effect of pruning on the cost of peeling Douglas fir, on poplar cultivation, on the census of woodlands, and on mycological and entomological work.

The Commission are to be congratulated on the Report on Forest Research, a document which everyone who wishes to keep himself informed as to the latest developments in forestry technique, or as to its possible trends in the future, should consult.

Textbook of Wood Technology, Volume II. *The Physical, Mechanical, and Chemical Properties of the Commercial Woods of the United States.* By H. P. Brown, A. J. Panshin, and C. C. Forsaith. 1952. McGraw–Hill Book Company, Inc., 95 Farrington Street, London, E.C. 4. Pp. 780. Price 85*s*.

Review by J. Bryan

VOLUME I of this textbook published in 1949 is a revision of the *Commercial Timbers of the United States*—a one-volume work published in 1940. In the revision the authors decided to segregate the subject-matter dealing with those properties of wood which govern its utilization, and this matter with considerable amplification and addition now appears as vol. ii of the revised work.

The authors have written this textbook for the use of foresters, engineers, architects, wood technologists, and students. Consequently much of the subject-matter is devoted to elementary physics and mechanics. With such a wide range of readers in view it is difficult to assess to what degree the readers are already familiar with these sciences, but many would find that much more space than necessary has been given to elementary science. For instance, it hardly seems necessary to devote a whole page to explaining that the stress in a short wooden column is the total load divided by the cross-sectional area. Although the authors have made considerable use of the highly concentrated factual data in the Madison Wood Handbook, many readers would no doubt have preferred a greater proportion of the text to have dealt with the practical aspects of wood technology and utilization and less with elementary physics and mechanics. Most of the line diagrams are concerned with these subjects and the volume is lacking in photographic illustrations and in this respect does not maintain the high standard of vol. i.

On the subject of wood technology this textbook is probably the largest in the English language. It is well printed and the subject-matter is presented in a logical and ordered manner which, in spite of its length, makes the book one of easy reference. With its large number of illustrative problems it will undoubtedly have its greatest appeal to the student, but it is probable that the price may deter many would-be purchasers in this field.

Wood Chemistry. Edited by L. E. Wise and E. C. Jahn. Second edition.New York: Reinhold Publishing Corporation, 1952. Two volumes, pp. 1277+indexes. London: Chapman and Hall. Price 120*s*. each volume.

Review by R. H. Farmer

THE first edition of this book, edited by L. E. Wise, appeared in 1944 and was then widely welcomed as the most comprehensive and up-to-date treatise on the chemistry of wood. Since that time rapid developments have taken place in many branches

of the subject, and in preparing a second edition of the book a complete revision of the text has been undertaken and considerable additions have been made to it. These have, in fact, been so great that it has been found necessary to publish the second edition in two volumes.

The book is written primarily for chemists, although much will be found in it to interest those concerned with other aspects of the science and technology of wood. The subject is treated mainly from the standpoint of the fundamental chemistry of wood and its components rather than of its use as a raw material for chemical industry. Thus few descriptions will be found of industrial chemical processes based on wood, such as chemical pulping and destructive distillation of wood, though the chemical basis of these processes is fully dealt with. The different chapters are written by specialists in the fields concerned, and this arrangement results in expert treatment of each subject.

The basic chemistry of the major and minor components of wood is dealt with in vol. i, which opens with a section on the growth, anatomy, and physical properties of wood. Although falling somewhat outside the main theme of the book, this section provides a useful introduction to the subject. The chemistry of the principal components of the wood cell-wall, namely, cellulose, the hemicelluloses, and lignin, is then discussed in detail. The chapters on cellulose and its derivatives provide a comprehensive review of present knowledge in this field, though it may perhaps be questioned whether it is desirable to devote so much space to branches of cellulose chemistry which have only an indirect bearing upon wood chemistry and which are fully dealt with elsewhere. Excellent accounts are given of the hemicelluloses and lignin by L. E. Wise and F. E. Brauns respectively, both these chapters having been completely rewritten. The final section of vol. i consists of a valuable and unique account of the wide range of types of organic compounds found among the minor, or extraneous, components of wood. Perhaps the outstanding contribution here is a discussion by H. Erdtman of the phenolic and other extraneous components of the heartwood of conifers and their relation to taxonomy.

In vol. ii the applied aspects of the subject are fully discussed. After a detailed account by A. J. Stamm of the surface properties of cellulosic materials, with particular emphasis upon wood-water relationships and their effect on the properties of wood, the chemical processes of carbonization, hydrolysis, and pulping of wood and bleaching of wood pulp are treated from the fundamental point of view. The succeeding chapter by W. G. Campbell on the biological decomposition of wood is a notable contribution to the book and contains much material, not previously assembled in one article, on the chemical changes involved in fungal decay of wood and its destruction by insects. Finally, there is a valuable critical review of the methods employed for the chemical analysis of wood and of the significance of the data thereby obtained, from which the broad conclusion may be drawn that, not only do the analytical methods in common use leave much to be desired, but it is extremely difficult to define precisely the various components which are to be determined.

The production is of a high standard and the book is very well documented, and is provided with a subject index but no author index. It is unfortunate that the availability of the book is likely to be limited on account of its high price.

British Commonwealth Forest Terminology. Part I. Empire Forestry Association, London, 1953. Pp. 163. 5½ in. by 8½ in. Price 21*s*.

Review by A. P. F. Hamilton

PART I comprises the branches of Silviculture, Management (including Mensuration), and Protection. Part II, dealing with Extraction, Utilization, and the Trade, will follow, and it is understood that there will be a Part III, Research Terminology.

The increasing number of scientific terms coming into use in forestry, and in particular those terms which are used in different senses in different regions, have underlined the need for putting our vocabulary in order.

A brief account of the events leading up to the publication of Part I may be of interest. In 1944 Professor Champion, when reviewing in the *Empire Forestry Review*, *Forestry Terminology*, published by the Society of American Foresters, suggested that the Empire Forestry Association should undertake a similar task. Accordingly the Association set up a Terminology Committee which held its first meeting in 1946. It was decided to use the American *Forestry Terminology* as a basis, which limited the inclusion of terms to '(1) those used in a special sense by foresters and (2) terms from other sciences and industries, the meaning of which may not be defined in other glossaries or texts likely to be readily available to the average forester'. The committee have, however, enriched the *Terminology* with a number of terms connected with soil science, ecology, genetics, and statistics without encroaching on the field of research and have thereby increased its value.

Sub-committees were formed to handle the various branches of forestry and at the same time the various units of the Empire were asked to set up terminology sub-committees and to supply lists of trees and definitions. In 1947 these sub-committees completed their work, Part II subjects excepted, and drafts were sent to all forest authorities in the Empire and to other bodies or individuals interested in the preparation of the terminology for criticism and suggestions.

Owing to delay in the preparation of Part II subjects, it was decided to proceed with publication of Part I, and in the period 1950–2 three proofs were received and submitted to close check.

As regards the sources from which Part I has been compiled, a large number of definitions from the American *Forestry Terminology* have either been used as they are or have been adapted to conform with Empire forestry usage. Two other sources were availed of: *Glossary of Technical Terms for Use in Indian Forestry* and *Glossary of Technical Terms used in Forestry Practice*, of Western Australia. A certain number of terms recommended for use in all parts of the Empire by the Third Empire Forestry Conference held in Australia and New Zealand in 1928 were retained.

In the glossary all subjects have been combined in one list, but silvicultural systems and thinning grades have been dealt with in some detail in appendixes. In the Introduction there is a brief list of glossaries of allied sciences for the use of those who may wish to look up definitions of more highly technical terms not included in the *Terminology*. Wherever necessary the authority for a definition is shown by an abbreviation and, similarly, local usage is denoted. These abbreviations, and those of a general nature, are listed at the beginning of the *Terminology*.

This small book contains a wealth of scientific information out of all proportion to its size, and those who know something of the difficulties of framing concise definitions will be able to measure the pains that have been taken by authors of the *Terminology* to produce so valuable a work. No quarrel can be found with the arrangement; some of the definitions may not be acceptable to everyone, but one of the chief objects of the *Terminology* is to put an end to controversy and this it will certainly do. The grateful thanks of all foresters in the Commonwealth are due to all those who have, without sparing themselves, given of their time and energy to produce this terminology which will not only be of great assistance to the individual forester but will also make possible a common language between foresters of the Commonwealth and beyond.

Empire Forestry Handbook, 6th edition. Empire Forestry Association, London, 1952. Price 15*s*.

Review by L. Chalk

MANY foresters consider this handbook to be just as essential a part of their professional equipment as a telephone directory. In the first place it contains a complete list of the names and grades of the Forest Officers in the Commonwealth, and in Burma, Eire, and the Sudan, and the staffs of all the institutions concerned with forest research and education. There is also a section describing the constitution and purposes of various bodies in this country connected with Commonwealth forestry, such as the Commonwealth Bureaux of Forestry and of Soil Science, the Colonial Products Advisory Bureau, the Forest Products Research Laboratory at Princes Risborough, and the Standing Committee on Commonwealth Forestry. Foreign institutions are dealt with separately, there being a list of the principal forest research organizations of the world (outside the Commonwealth) and a sub-section on F.A.O.

Two other very useful reference sections are those devoted to the Commonwealth Societies with forestry interests, and to forestry periodicals. The former includes the names of officers, details of membership, meetings, and publications. The list of world publications connected with Forestry claims only to be a good 'selected list', but even so includes the names of over eighty publications. There is also a section containing 'useful information', such as the conversion of English into metric and local measures, methods of measuring round timber and conversion factors, gradients, compound interest tables, &c.

All this information makes the handbook indispensable as a directory, but it is much more than that. The sections on the forest resources of the world by Sir Hugh Watson and on the nomenclature of timbers on the British market bring together into a convenient form data that are extremely inaccessible to the ordinary forester. The former, based on official statistics, shows in tabular form the areas of forest of various types in different countries, and the corresponding areas of land used for other purposes, together with such statistics as density of population and acreage of forest per head of population. Estimates of growing stock in accessible productive forests are given separately for conifers and hardwoods, and include standing volumes, increment, and fellings. The list of timbers includes the scientific name and author (with synonym where there has been a recent change), the standard and other common names, and sources of supply. As an up-to-date and thoroughly reliable list of scientific names this is invaluable.

The handbook is revised at irregular intervals and the last edition was in 1946. Some alterations have been made in the 1952 edition, apart from bringing the lists up to date, and the number of pages has increased from 241 to 300. Among the new features are a list of hardwood species imported in the log from West Africa with their densities and feet per ton, and a section on the scientific naming of plants, the latter including the English equivalents of the common Latin or Greek words used in the scientific names.

continued from inside front cover]

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Fuller details of qualifications may be obtained from the Secretary.

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Printed in Great Britain at the University Press, Oxford, by Charles Batey, Printer to the University